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Master Thesis

Photogrammetric determination of body length and body mass in Galápagos sea lions (*Zalophus wollebaeki*)

by

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To my family

Abstract

Measuring body morphometrics of large mammals is difficult, time consuming and requires a lot of equipment. Photogrammetric measurements are less intrusive, faster and only a single researcher with a bag full of equipment is necessary. In the present study a photogrammetric method to determine the body length and mass of Galápagos sea lions (*Zalophus wollebaeki*) is developed and evaluated. A photogrammetric method developed for body length calculations of whales (Jaquet 2006) is used, extended and improved. Pictures of animals are taken and the distance between camera and animal is used for scaling. For calibration of the camera and validation of the method some animals are captured and body parameters are measured manually. Accuracy (R^2, s.d.) and precision (mean deviation of manual and photogrammetric values) of the method are evaluated. The application of this photogrammetric method derives highly accurate (adult length R^2 = 0.777, s.d. = 3.71; mass R^2 = 0.867, s.d. = 6.26) and precise (mean deviations: length = 2.02, mass = 5.29) calculations of body length and body mass for adult and offspring Galápagos sea lion. Correlations between manually measured and photogrammetrically calculated values are found to be highly significant (p-values: length: $p = 0.001$, mass: $p = 0.0001$). Additionally the impact of several factors (while taking the picture, while analyzing or position of the animal in the picture) influencing the accuracy of this method are analyzed. Based on these analyses, recommendations are given for the application of the photogrammetric method to determine body length and mass of sea lions.

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List of abbreviations

PG	Pictures taken from ground level
PE	Pictures taken from elevation
L_{mes}	Length manually measured
L_{cal}	Length photogrammetrically calculated
M_{mes}	Mass manually measured
M_{cal}	Mass photogrammetrically calculated
$\bar{x}$	Mean
#	Number
s.d.	Standard deviation
R^2	Coefficient of determination

1. Introduction

During their life time animals face several trade-offs concerning allocation of resources to the three main processes for individuals namely maintenance, growth and reproduction (Gadgil and Bossert 1970). Natural selection shapes these trade-offs and thereby individual and species specific life history strategies evolve. The challenge in studying life history strategies is to determine the impact of intrinsic (individual quality, fecundity) and extrinsic (variation in weather and food supply) factors (Pomeroy et al. 1999). To get a better understanding of these factors and the mechanisms behind them it could help studying animals which are living in a highly variable environment. A change in food supply influences energy availability and individuals have to face trade-offs of energy allocation. Studying those changes could help clarifying the impact of individual or environmental factors on life history strategies. The Galápagos sea lion lives in a highly variable and unpredictable marine environment (Mueller 2011). Normally in summer the water currents change in the equatorial pacific area and the impact of the Humboldt Current from the south is strengthened. This current brings cold and food rich water and forms an excellent livelihood for a lot of animals including the Galápagos sea lion. But every few years the impact of the Humboldt Current weakens because of a change in the trade winds. Then another current from the east pacific area carries warm water with low food availability to the Galápagos Islands, a phenomenon which is called "El Niño" (Bjerknes 1961, Rasmusson and Wallace 1983). This drastic change in food supply is assumed to highly influence the life cycle of the Galápagos sea lion. They need to cope with a lot of unexpected and drastic environmental changes (Trillmich and Limberger 1985) and therefore they represent an optimal subject for studying life history strategies.

A common way of studying life history strategies is by measuring individual body parameters and calculating and comparing body condition indices. Body condition refers to the energetic state of an animal (Schulte-Hostedde et al. 2005) and indicates how well an individual can cope under certain environmental conditions. Comparison of body condition can therefore indicate how individual differences influence the allocation of energy, additionally to maintenance, on growth and reproduction. Comparing these individual differences can indicate the impact of intrinsic and extrinsic factors on certain history strategy. Several different ways of calculating animals' body condition are known (Jakob et al. 1996) but in general it is a relationship between body length and mass.

Measuring body length and mass of large mammals can be difficult. Direct measurements by catching animals are time consuming, can be dangerous for the animal (Bell et al. 1997) and require the transport of heavy equipment (Gales and Burton 1987, Boyd et al. 1993). Photogrammetric measurements, defined as measurements on photographs (Baker 1960) are less intrusive for the animals (Proffitt et al. 2008). This was investigated in a previous photogrammetric study of monk seals (McFadden et al. 2006). No visible disturbance in form of physical reaction of the seals could be spotted in 93 percent of the photographic attempts. Other benefits of the use of photogrammetry are that a single photographer can collect a huge data set with a small amount of equipment and in a short time period.

One of the first photogrammetric studies of body length is on Southern elephant seals (Laws 1953 as cited by Bell et al. 1997). Since then several studies were conducted especially on whales (Bowhead [Cubbage and Calambokidis 1987; Cosens and Blouw 2003], Fin whales [Ratnaswamy and Winn 1993], Sperm whales [Jaquet 2006], Killer whales [Durban and Parsons 2006], Hector's dolphins [Webster et al. 2010]) but also on African elephants (Douglas-Hamilton 1972, Hall-Martin and Rüther 1979), Western Gorillas (Breuer et al. 2007), Whale sharks (Rohner et al. 2011) and pinnipeds (Northern elephant seal [Haley et al. 1991], Southern elephant seals [Modig 1996, Bell et al. 1997], Hawaiian monk seal [McFadden et al. 2006], Steller sea lions [Waite et al. 2007], Galápagos sea lion [Bachelor thesis, Zein 2010; PhD thesis Müller 2011]).
Photogrammetric body mass determination is mostly used in large pinnipeds (Northern elephant seal [Haley et al. 1991], Southern elephant seal [Bell et al. 1997, de Bruyn et al. 2009], Weddell seal [Ireland 2006, Proffitt et al. 2008]) and two smaller pinniped species (Hawaiian monk seal [McFadden et al. 2006], Steller sea lions [Waite et al. 2007]).

There are several different methods of photogrammetrically estimating animals' body parameters. Common in all methods is the need of a mechanism for scaling the object within the picture. To photogrammetrically estimate animals' body length some studies determine the distance between the animal and the camera and calibrate the cameras with an object of known length (studies conducted with one camera: Breuer et al. 2007, Jaquet 2006, Douglas-Hamilton 1972; two cameras: Cubbage and Calambokidis 1987, Ratnaswamy and Winn 1993). The derived equation from calibration is then used for further length estimation. A stereo-photogrammetric technique for length estimation is used with two stereo cameras separated in space (Hall-Martin and Rüther 1979). Length can be derived by modeling the measured parameters in a three dimensional coordinate system. Additionally complex transformations due to relative and absolute orientation of the animals need to be done in these studies. More recent studies use two parallel lasers for scaling. The lasers projects dots separated by a known distance on a part of the animals' body (Webster et al. 2010, Durban and Parsons 2006). This line segment can be used to calculate the animals' body length.

In previous studies only one method for photogrammetrically estimating animals' body mass was used. For this method one camera and a scaling pole is needed (Haley et al. 1991, Bell et al. 1997, McFadden et al. 2006, Ireland 2006, Waite et al. 2007, Proffitt et al. 2008, de Bruyn et al. 2009). Before taking the picture of the animal, a pole with known length segments is placed near the object. This pole can be used to convert image units (pixels) to size units (centimeters). For photogrammetric mass estimation some previously photographed animals have to be captured and weighed to generate a correlation between picture parameter (side area, front area, body length or volume) and measured mass. This equation derived from the correlation can be used for photogrammetric mass estimation but is specific for the species used in the correlation due to species specific body characteristics.

Studies vary in the use of different parameters of the animal in the picture. Most commonly a correlation between animals' side area to measured mass is used. However models of several variations in the use of girth, length, side area and front area are also used (Haley et al. 1991, Bell et al. 1997, McFadden et al. 2006, Ireland 2006, Waite et al. 2007, Proffitt et al. 2008, de Bruyn et al. 2009). A different approach calculates the animals' volume from a three dimensional model of the animal (Waite et al. 2007, de Bruyn et al. 2009). For this method several pictures of the animal have to be taken from different angles and also a scaling stick has to be included in the pictures. Then markers found on the animal (Waite et al. 2007) or the ground (de Bruyn et al. 2009) are used for picture comparison and deriving a three dimensional model of the animal. There is one big disadvantage of the studies which calculate a three dimensional model of the animals. This method is not practicable in the field since there have to be several pictures taken from around the animal. This is not possible for most pinnipeds species because of nervous or offensive behavior and resulting movements of the animals. To solve this problem, animals were either sedated or under behavior control in captivity while taking the pictures in the previously mentioned studies.

The accurateness of the photogrammetric estimation of animals' body length and mass varies greatly over different pinniped studies. In literature the mean deviations from photogrammetrically estimated and traditionally measured animals' body lengths varied from 2.4 percent (Modig 1996) up to 14 percent (95 % of confident interval [CI]; McFadden et al. 2006). The best photogrammetric estimation of animal body mass had a deviation from 1.34 to 3.83 percent (95 % of CI) in the study of de Bruyn et al. (2009). The worst deviation values of animals' mass calculation range from 12-25 percent in adults (95 % of CI, Haley et al. 1991) and there is a mean deviation of 25.9 percent in offspring (Ireland et al. 2006). There are studies where low accuracy values are sufficient. For example, when differences between male size and position in a harem in southern elephant seals (Modig 1996) are studied, it might be sufficient categorizing two or three size classes and comparing them. In this case the method of estimating animal body length does not need to be highly accurate. But for calculating body condition the accuracy of body measurements have to be as high as possible. The calculation of body condition is based on the residual differences of a correlation between body mass and body length (Schulte-Hostedde et al. 2005). A minor deviation in one parameter can have a big impact on the calculated residual and can make further studies on body conditions difficult. Therefore, while developing

photogrammetric techniques researchers have to pay attention to the accuracy of the photogrammetric calculation of body length and body mass.
For measuring the accuracy of photogrammetric measurements animals should be captured and morphometric analyses should be done manually for comparison. However, there is also a deviation between the single measurements while manually measuring the length and the mass of an animal. In the study of Waite et al. (2007) they checked for variation of measurement techniques of captive Steller sea lions. Several staff members of an aquarium had to measure the length of the same individual. Differences between different staff members' measurements of the length of a juvenile animal were up to 6.5 cm (approximate body length 100 -200 cm). In the field, measurements of body parameters of wild animals can be influenced by several parameters. Defensive behavior combined with a lot of movement of the animal can have a big impact on length and mass measurements. If the animal is sedated it could be that the relaxation of the muscles have an impact on animal's body length. This variance of manually measuring animal body length and mass has to be considered in studies of the accuracy of photogrammetric measurements.

The quality of photogrammetric measurements in pinnipeds is influenced by several factors. One problem is a difference in surface characteristics. De Bruyn et al. (2009) found overestimation of photogrammetrically estimated body length on even undergrounds whereas photogrammetric measurements of animals on uneven substrates were more accurate. A different study (Bell et al. 1997) stated that animals had to lie on packed surfaces rather than on grass. The reason for this is that animals' contours are difficult to trace in surfaces like grass. Another problem is the position of the animal. In a study on Hawaiian monk seals (McFadden et al. 2006) the authors defined different quality classes of pictures in which animals vary in position. They showed that pictures of animals lying on the side or on the back cause underestimation of animals' surface area and perimeter and have to be excluded. Body posture was also investigated by Waite et al. (2007). They found that an animal has to lie perfectly flat and straight for accurate photogrammetric length measurements. Increasing the attention on factors influencing the accuracy of photogrammetric measurements can help improving this method.

The Galápagos sea lion seems to be an optimal subject for studies of life history strategies but it proved to be difficult to obtain morphometric data. Photogrammetric techniques for determining body length and body mass provide a good alternative to traditional measuring methods. By now, there is only one study on photogrammetrically estimating body length and body mass of sea lions (Waite et al. 2007). However, the technique used in this study is not practicable for wild animals since several pictures have to be taken around the animal. This very likely results in movement of the animals due to nervous or offensive behavior. Therefore, this technique does not provide an alternative for studying morphometrics of the Galápagos sea lion. A large historical background on photogrammetrically estimating pinnipeds' body length and mass provides a promising and fundamental knowledge (Northern elephant seal [Haley et al. 1991], Southern elephant seal [Modig 1996, Bell et al. 1997, de Bruyn et al. 2009], Weddell seal [Ireland 2006, Proffitt et al. 2008] and Hawaiian monk seal [McFadden et al. 2006]). But all of these studies were conducted on phocids (elephant seals, weddell seals, monk seals) which have major differences in body characteristics compared to otariids (sea lions). The study on sea lions by Waite et al. (2007) can be used for a comparison between photogrammetrically estimating morphometrics of phocids and sea lions but does not serve as eventual solution on how to photogrammetrically estimate animals' body morphometrics in the wild. Therefore a photogrammetric length and mass determination technique which is applicable in the field will be designed and evaluated for the Galápagos sea lion.

The photogrammetric technique used in this study will be based on the procedure designed by Jaquet (2006). The basic method consists of taking the picture of an object and measuring the distance between the camera and the object with a range finder. Then camera needs to be calibrated with an object of known length and over different distances. Therefore the pixel within the object in a picture can be scaled to a certain length or side area. One benefit of the use of this procedure in pinnipeds is the elimination of the error developing from the use of a stick for scaling the pixel within a picture. In former studies the scaling stick is hold by an observer over the body of the animal. If the position of the scaling stick is varied it can highly influence the accuracy of the photogrammetric measurement.

Therefore the scaling will be done in the present study by measuring the distance between object and camera and calibrating the camera. This method is already used in a former study of photogrammetrically estimating the length of Galápagos sea lions (Bachelor thesis, Zein 2010; PhD thesis Müller 2011). In this study it is found that the photogrammetric length estimation can be used to derive the length of the animals. A correlation between photogrammetrically and traditionally measured length was greater than 0.93. But the correlation coefficient was highly influenced by the range of the data set and outliers. Since high ranges of animals' body length were used further attention has to be drawn to the accuracy and precision of photogrammertic estimation of the length of the Galápagos sea lion. In the same study the repeatability (by Lessells and Boag 1987) of analyzing the same pictures by different observers is analyzed. This repeatability was greater than 0.8 which shows good accuracy of the tracing of the animals in the picture by different observers. A method for minimizing the impact of the tracing even more might further improve the accuracy of the photogrammetric measurements. Therefore a program including an edge based segmentation technique (Lankton and Tannenbaum 2008) is used to decrease the impact of the person tracing the animal in the picture.

1.1 Aim of this study

This photogrammetric method is applied to solve and clarify the following four main points:

1. Designing and evaluating a technique for photogrammetrically estimating the body length and body mass of the Galápagos sea lion. Therefore a part of the procedure of Jaquet (2006) is used. For analyzing the pictures new programs are written for improving the length estimation and deriving a mass estimation technique.
2. How big is the impact of the camera calibration? To address this question three different calibration methods are used and compared (one calibration specific for length, one specific to length and area and one directly using the parameters of the animals).
3. What else influences the accuracy of the photogrammetrically estimated body length and mass?
    (a) Factors while taking and analyzing the pictures
    The impact of a variation in distance and angle between camera and object while taking the picture and a variation in tracing the animal within the picture are evaluated.
    (b) Factors within the pictures
    Pictures are categorized depending on body form, body position and surface characteristics. Categories are evaluated by comparing the accuracy and precision of photogrammetrically estimated body length and mass of adults and offspring.

4. Application of the photogrammetric method:
   Can the photogrammetrically estimated body length and mass be used for estimating animals' body conditions? To address this question body conditions are calculated for manually measured parameters and for the photogrammetric estimated values and the results are compared.

2. Materials and Methods

2.1 Study subject

The Galápagos sea lion belongs to the family of the Otariidae. They are nonmigrating and live in a highly variable marine environment due to the El Niño phenomenon. This affects the food availability every few years. Therefore the animals need to face a trade-off of energy allocation and a higher mortality risk in years of El Niño. In general, the sea lions rest on land and forage at sea. They are polygynous and have sexual size dimorphism. The males can reach a size up to 250 kg and 270 cm. And the females are comparatively smaller than the males. Female size ranges from 130 to 170 cm and from 60 to 100 kg of body masses. Also the males tend to have a fatter neck a wider shoulder area than the females. Sex differences in terms of size were also found in studies of their closet relative the California sea lions. Male offspring are significantly larger (Ono et al. 1987, Ono and Boness 1996) and heavier (Luque and Aurioles-Gamboa 2001) than female offspring at birth. Sexually maturity is reached at the age of five to six years. Since for some animals the exact birthdate is unknown and in general the weight of newly sexually matured animals is known, animals over 40 kg of mass were treated as adults. Pups are born in the autumn season and are on average lactated for about a year. The size range of pups and immature are 15 to 40 kg and they can reach up to 130 cm of length.

2.2 Data collection and analysis

2.2.1 Data acquisition in the field

Data was collected on Camaño (0°45´S, 90°16´W) a little islet in the Galápagos archipelago. There a long term study on the Galápagos sea lion is being conducted since 2003. Since then animals are captured, measured and tagged (Wolf et al. 2005, Wolf and Trillmich 2007). Therefore the majority of animals can be individually recognized. Data used in this study was mainly collected in the spring season of March/April 2012 (mass and length data) but data collected in previous autumn and spring seasons were also used (length data).

To model and test body length and body mass of individual Galápagos sea lions, it was necessary to measure and weigh some photographed individuals to create a calibration curve for length/weight and the calculated photogrammetric length/area in pixels of an individual. Animals were captured (Fuhrman Diversified, USA), weighed (offspring: spring balance; Pesola®, Schweiz, ± 0.1 kg; adults: Kern, HUS 300K100, ± 0.1 kg) and standard length (Committee on Marine Mammals 1967) and sex were determined. Individual parameters were stored in a data base (Microsoft Office Access database 2007).

Pictures of well stretched out, resting animals were taken (Canon Eos D-300®, focal length 55 mm) from the side approximately at a 90 degrees angle to the longitudinal axis (figure M1). Additionally attention was paid that the animal was positioned in the center of the picture while taking photographing. The distance between the camera and the animal was measured by a distance meter (Leica, Disto™ A5). For minimizing the estimation error, several pictures were made of each individual and the mean of derived estimates for the various measurements was calculated.

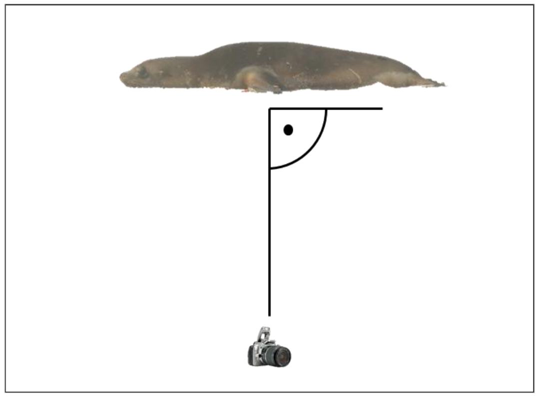


Figure M1 Illustration of the angle between camera and animal.

Pictures of individual Galápagos sea lions were taken from two different heights (picture type; see figure M2) either from the ground level (only in spring season 2012; pictures ground level = *PG*) or at the photographers eye level while standing (pictures elevated = *PE*).

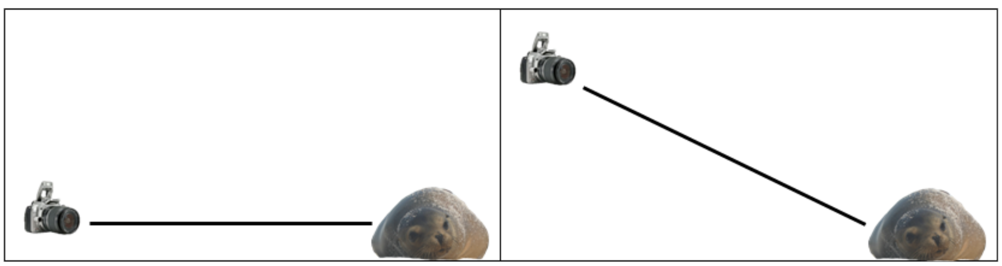


Figure M2 Visualization of picture types. Illustrated on the left side are pictures taken from ground level (PG) and on the right side, pictures taken from elevation (PE).

2.2.2 Picture parameter

For comparison of animals' body length and mass the animals had to lie in the same position. However, there was a high variation of animals resting position. For evaluating the quality of the picture in terms of animals' positioning several parameters were defined.

In the first categorization the body curvature of the animals in the pictures was defined (body form, figure M3). In a former study it was found that only pictures of animals in a straight body form (front and back end bent approximately less than 15° from a straight line through the longitudinal axis of the body; Zein 2010) could provide repeatable results in photogrammetric length calculations. Therefore animals in a straight resting position (<15° curvature) were defined as body form *good* (figure M3, left). Since there could be other results for photogrammetric mass calculations other body forms were also considered. If the entire back end of the animal was bended under the body the body form was called *bent* (figure M3, middle). All the other forms of animals bodies were summarized in one category, called *bad* (figure M3, right).

Figure M3 Example pictures of animals in different body forms (*good*, *bent and bad*; from left to right).

A second categorization was done concerning the side of the body which the animals were lying on. This category was called position (figure M4). The animal in the picture was either lying on the *belly* (figure M4, left), on the *side* (figure M4, middle) or on the *back* (figure M4, right).

Figure M4 Animals lying in the position *belly*, *side* and *back* (from left to right).

The photogrammetric determination of body parameters was also affected by other factors in the picture. Three different types of possible problems (problem pictures, figure M5) were defined. If an animal was lying in the grass in a picture it was difficult to mark the contours of the animal. Therefore the first defined problem was called *grass* (figure M5, left). A second problem was arising from the position of the head. Since a slight movement or rotation of the head could have an impact on length and mass calculations a second problem was defined called *head* (figure M5, middle). There were a high number of possible problems within a picture but the number of categories should be limited because too many categories decrease the sample size within a single category. Therefore, only one more problem category was defined called *another* (figure M5, right). Included in this category were pictures of animals lying in a small hole, which had a part of the body covered by another animal, stones or sand or pictures with animals in unusual body forms.

Figure M5 Pictures of animals in the category *grass* problem, *head* problem and *another* problem (from left to right).

2.2.3 Calibration

Three different calibration methods were evaluated (called *pole, cardboard* and *animals*) and will be explained in the following.

For the calibration method *pole* a tree trunk was already measured and photographed in the field in previous years (figure M6). Pictures were taken from elevation (*PE*) and from different distances and were analyzed with the program Image J (Müller PhD thesis). The number of pixels on a line ($\text{pixel}_{\text{length}}$) from the beginning to the end of the pole was measured. The pixel data was used to derive a linear regression:

$$(1)\ \text{Length of the pole}/\text{pixel}_{\text{length}} = a*\text{distance}-b$$

This equation can be converted to get the length of the pole:

$$(2)\ \text{Length} = (a*\text{distance}-b)*\text{pixel}_{\text{length}}$$

The second equation was used for further photogrammetric calculations of the body length of sea lions. For photogrammetric mass calculation the area of the object was calculated using the squared equation (2).

Figure M6 Picture of a tree trunk which is used for the calibration method *pole*.

The *cardboard* calibration was done indoor using a 140*25 cm cardboard (figure M7). The procedure was the same as for the pole but pictures were taken at the height of the object (*PG*). Equations were calculated for length and for area using number of pixel on the horizontal axis (3) and area in pixel ($pixel_{area}$) (4). The derived equations of the calibration method *cardboard* were used for photogrammetric calculations.

$$(3)\ Length = (a*distance-b)*pixel_{length}$$

$$(4)\ Area = pixel_{area}/\ (a*distance\hat{\ }b)$$

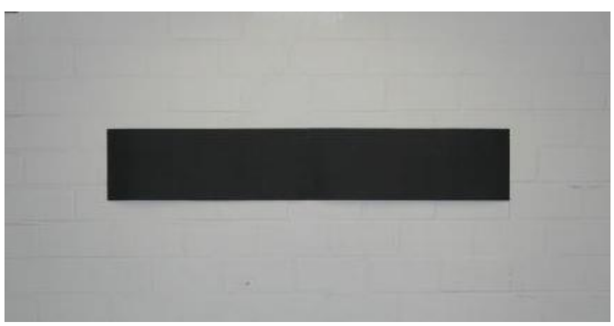


Figure M7 Example of a picture for calibration from the cardboard**.**

To derive an equation for photogrammetrically calculating animals' body mass from the calibration methods *pole* and *cardboard* the calculated side area of the animal's body needed to be correlated to the measured body mass of the animals. Therefore half of the photographed animals were used for this correlation. The derived equation was used for further mass calculations of previously photographed and weighed individuals.

In the third calibration method *animals* the parameters length and area in pixels were directly correlated with the measured body length and body mass. The derived equations were converted for further photogrammetric calculations of animals' body length (5) and body mass (6).

$$(5)\ \text{Body length} = (a*\text{distance}-b)*\text{pixel}_{\text{length}}$$

$$(6)\ \text{Body mass} = (a*\text{distance}^{\wedge}b)*\text{pixel}_{\text{area}}$$

For a precise calibration in the method *animals* half of the pictures taken in the field were selected and additionally pictures including animals with problems and lying in a *bent* or *bad* form were excluded. The selection of the pictures was done focusing on the distances between camera and animal. To create an equal as possible distribution of the distances pictures were sorted by distance and every second picture was selected for calibration. For body length calculation no impact of animals' body position was expected since length of the animals body should be equal from every side. Therefore all positions were included. For mass calibration only the position *belly* was used because of a high expected impact of the other positions on calculations.

2.2.4 Pixel calculation

In a previous study of photogrammetric body length measurements (Zein 2010) the analyses of the picture parameter were done manually with the program ImageJ. This was very time consuming. Also this program does not provide an exact method for measuring the area of an object with irregular contours. Therefore a new program was developed. From previous experience I assumed that the program had to meet general requirements such as being easy and fast to apply and being able to handle a large data set. Those were some of the challenges while deriving the following programs. Another challenge was to exactly find and calculate the contours of the animal in the picture.

For calculating area and length in pixel of an animal in the picture a MATLAB (MATLAB R2011b) program was written (program “main menu”, see appendix; by Prof. Dr. J. Engelmann and Beate Zein). The first step for the user of the program was to choose the relevant part of the picture which contained the body of the animal with a rectangular tool (figure M8, top). Then the user had to mark the contour of the animal’s body by clicking several times along the body contour until the mask was closed (figure M8, middle). Animals’ side and back flipper were excluded from calculations because of high variability of flipper position and a high expected impact on side area and body length calculations. The program separately saved the relevant picture part (I2) and the part of the picture containing pixels of the roughly marked body part of the animal (mask). To reduce the error of the following tracing the contrast between I2 and the mask was increased. An edge based segmentation technique (Lankton and Tannenbaum 2008) was used for tracing the contours of the animal (figure M8, bottom). Every picture had to be checked for erroneous tracing and in case of a wrong calculated contour the mask of the animal had to be clicked again with a higher quantity of clicks on the respected contour part. Finally a statistic MATLAB function (regionprops, see program main menu in appendix) was used to derive the area, perimeter, and major and minor axis length in pixel of the animals’ body within the picture. The results were saved in an Excel file (MS Excel 2010).

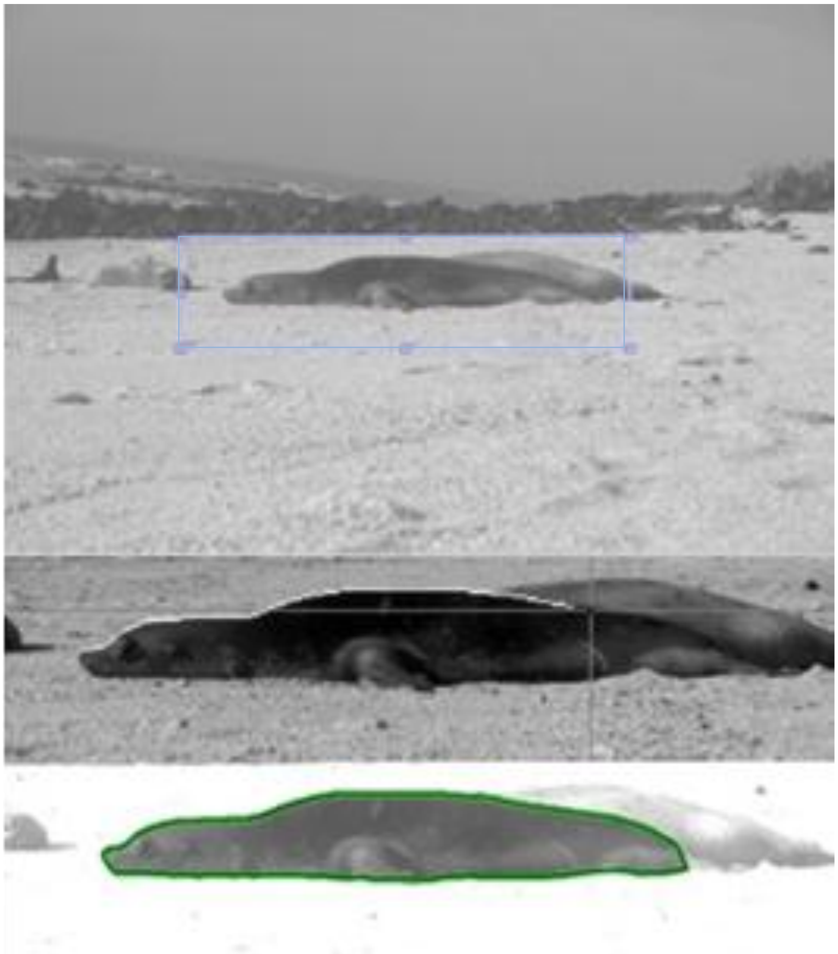


Figure M8 Pictures show the relevant steps of analyzing the pictures. Top: Choosing the relevant picture part. Middle: Marking the animals contour excluding the flippers. Bottom: Picture of an animal after the contour is traced.

A second program was written for the calculation of the animals' side area and body length (program "area-length calculation", see appendix).

The information of the pictures and the data measured in the field were stored in two different Excel sheets. The assembling of the sheets by hand would have been very time consuming because of the variable number of pictures per individual. A third program was written (program "combine", see appendix) which searched for identical animal identification numbers in both sheets and combined the information in one new Excel sheet.

For classification of the pictures three MATLAB programs were written (programs “classification 1-3”; see appendix). Those programs displayed every image and opened a menu in which the user could classify the parameter of the animal in the picture (body form, position, picture problems). The picture name and the selected parameters were saved in Excel files.

2.3 Validation

2.3.1 Testing for errors in data acquisition

Tests of the impact of variation in taking the pictures were conducted to evaluate how error-prone the two dimensional photogrammetric method for length and area calculations was. The impact of the distance and angle of the camera to the object (see figure M9) and the impact of the object angle (object rotation through the object center vertical to the image plan, figure M9) were considered. Therefore several pictures of the cardboard varying in those parameters were taken. To evaluate the impact of those parameters on the calculations, the deviation between the calculated and the measured length (length measured = L_{mes}; length calculated = L_{cal}) and mass (mass measured = M_{mes}; mass calculated = M_{cal}) was calculated.

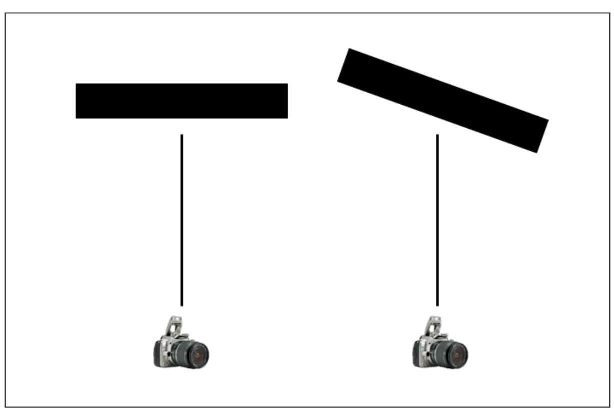


Figure M9 Illustration of a change of the angle of the object.

During the process of extracting the pixel information from the pictures the contours had to be marked by hand. This procedure of marking the contour of an animal in the picture was repeated several times to test for the impact of variation in clicking for contour determination on the calculated parameters.

2.3.2 Evaluation of calibration methods and picture type

The remaining half of the pictures, which has not been used in the calibration method *animals,* was used to calculate animals' body length and body mass. Body parameters (length and mass) for an animal in the picture were calculated for every method (*pole*, *cardboard*, *animals*) and separated for picture type (*PG*, *PE*). Then comparisons between calculated and measured body parameters were made.

For selection of the best calibration method and picture type for calculations of animal body length and mass, three analysis parameters were evaluated. Because several pictures were taken from one individual over different distances, a generalized linear mixed model (GLMM; Pinheiro and Bates 2000) was calculated using the program R (R i386 2.15.2; R Core Team 2012). The evaluation of the accuracy of the calculated measurement compared to the measured body parameter was derived using the coefficient of determination (R^2, Steel and Torrie 1960) and the standard deviation of the model. Precision was determined with a measurement of the mean deviation from the calculated and measured body parameters.

The calibration method and picture type with the most precise and accurate body length and mass calculation was chosen for further calculations.

2.3.3 Evaluation of parameters of pictures, animals and season

To develop a guideline for photogrammetric body length and body mass determination it was evaluated which parameter of the pictures had a negative impact on the calculation of body length or body mass. The parameter of the animal in the picture (body form, position and problem *pictures*), picture type (*PG*, *PE*) or a separation in time (greater than 3 month, *season*) while taking the picture and capturing the animal were used.

2.3 Validation

Two different approaches for evaluation were taken because of a high number of interactions between different animal parameters and problems. They were called the *all picture analysis* and *best picture analysis*.

In the *all picture analysis* all pictures taken in the field were used and the impact of individual parameters on the quality of animals' body length or mass calculation was considered. For the calculated body length or mass of all pictures the accuracy and precision were calculated in the same way as for the evaluation of the different calibration methods. Then pictures with one type of individual parameter were excluded and accuracy and precision were calculated again. This was done for picture type, body form, position, *season* and pictures in the category problems. For qualification of the impact of different parameters on the photogrammetric method, the values of the calculation of all pictures were compared to the values of all pictures with the particular exclusion of different parameters.

The *best pictures* were defined as pictures taken from ground level, with an animal lying on the *belly* in a straight way (body form *good*) without any kind of problems. Furthermore, taking the picture and weighing the corresponding animal had to be done in the same season. As a starting point for the *best picture analysis* only perfect pictures were used for body length and mass calculations. Accuracy and precision were determined from comparing the calculated to the measured parameters in the same way as explained above. Then pictures of individual parameters (body form, position, *season* and problem) were included and calculations were repeated. Finally the values of the different calculations were compared for evaluating the impact of the defined picture categories.

For studies which are going to use body condition calculations, the body length and mass calculation had to be as precise as possible and only calculations deriving the highest accuracy and precision were used. The corresponding pictures were selected and a GLMM was conducted to measure the accuracy and precision of the final model. The model for calculated and measured body length and mass was checked for significance ($p<0.05$) and for significant influences of position, distance and sex.

2.4 Application to body condition

A common method for evaluating animals' body condition is plotting body length over body mass and comparing the residuals (Jakob et al. 1996, Schulte-Hostedde et al. 2005). This method shows whether individuals are heavier or lighter than an average individual of a certain size. It was tested if the photogrammetric length and mass calculation was accurate enough for residual body condition calculations. Comparisons of measured and calculated body conditions were done in Microsoft Excel. The body length and mass were plotted and the residuals were calculated and compared.

3. Results

This chapter is separated in two parts for length and mass calculations.

3.1 Results length measurements

Two dimensional photogrammetric body length estimations were found to be best when calculated separately for different age classes as defined (GLMM, $p = 0.0475$; $n_{adults} = 162$, $n_{offspring} = 91$).

3.1.1 Calibration for length

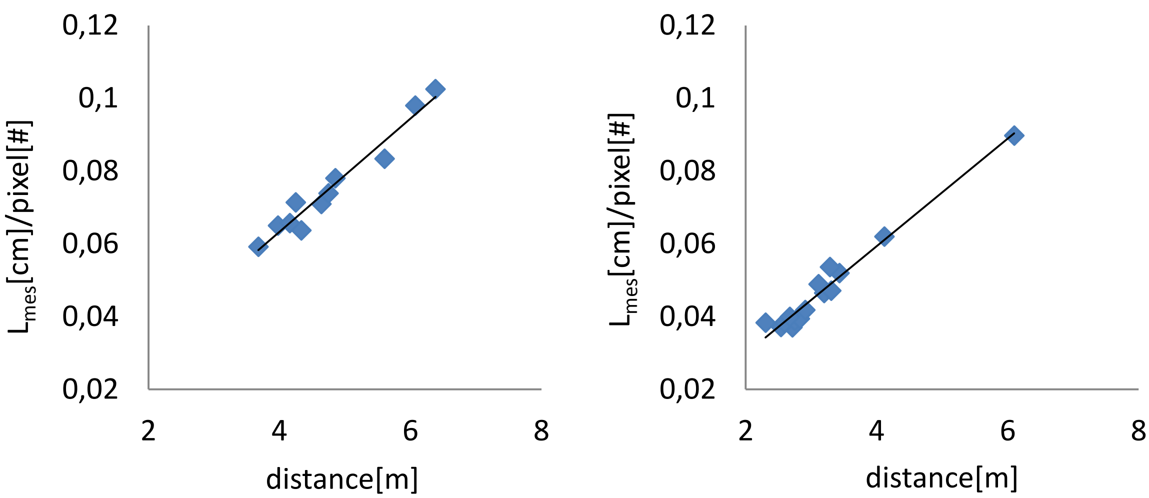
a) Deriving the calibration methods

Three different calibration methods were calculated by plotting measured length divided by the number of pixels lying on the major axis length of the object (picture) over the distance between camera and object. The resulting straight line equations were checked for the degree of correlation (R^2 in table R1). The equations for calculating the length of objects while using pictures can be derived by conversion of the straight line equations (table R1).

All calibration curves were highly correlated and the best correlation values were found for the standardized objects *pole* and *cardboard*. A drop in the coefficient of determination appeared with the pictures taken from elevation. Calibrations using *animals*' body length for calculation were found to have an unbalanced distribution of the distance data (figure R1). Especially in offspring there was a lack of samples for distances above 4 m (figure R1b).

Table R1 Body length equations for different calibration methods and different camera positions (*PG* and *PE*). Equations were derived from plotting length [cm]/pixel [#] over distances [m].

method	equation	R^2
pole	L_{cal} = (0.0139*distance-0.0016)*pixel	0.999
cardboard (n = 10)	L_{cal} = (0.0121*distance-0.0011)*pixel	0.999
animals - adults		
PG (n = 11)	L_{cal} = (0.0156*distance+0.0009)*pixel	0.955
PE (n = 15)	L_{cal} = (0.0149*distance-0.0034)*pixel	0.890
PG+PE (n = 26)	L_{cal} = (0.0141*distance+0.0045)*pixel	0.913
animals - offspring		
PG (n = 15)	L_{cal} = (0.0148*distance+0.0003)*pixel	0.971
PE (n = 7)	L_{cal} = (0.0081*distance+0.0192)*pixel	0.768
PG+PE (n = 22)	L_{cal} = (0.0109*distance+0.0118)*pixel	0.827



a) adults **b) offspring**

Figure R1 Calibration curves using animals' body length. Separated for adults (a; R^2 = 0.955) and offspring (b; R^2 = 0.971) and only for pictures taken from ground level (*PG*).

b) Influence of calibration methods on photogrammetric body length calculations

Three different calibration methods were used for length calculations and therefore every picture of an animal was analyzed three times. Body lengths of the animal in the picture were calculated by using the equations derived from the three calibrations (see table R2). The accuracy and precision of the length calculation were compared for the calibration methods by comparing the measured and calculated body length of an animal.

Table R2 Evaluation of the accuracy and precision of the three different calibration methods (*pole*, *cardboard*, *animals*) and different picture types (*PG* and *PE*) for the photogrammetrically calculated body length. All three body positions were used for calibration and validation.

	picture type	calibration method	n individuals	n pictures	R^2	$\bar{x}$ deviation L_{mes} & L_{cal} [%]	s.d. [%]
Adults	PG	pole	9	11	0.741	-11.00	-3.17
		cardboard	9	11	0.742	-22.11	-2.71
		animals	9	11	0.747	3.71	-3.23
	PE	pole	9	15	0.740	-7.21	-5.91
		cardboard	9	15	0.737	-18.80	-5.17
		animals	9	15	0.754	-2.99	-6.23
	PG+PE	pole	17	25	0.363	-7.07	-5.74
		cardboard	17	25	0.360	-18.67	-5.04
		animals	17	25	0.314	3.37	-6.81
Offspring	PG	pole	14	14	0.722	-12.39	-3.34
		cardboard	14	14	0.725	-23.10	-2.89
		animals	14	14	0.730	-2.41	-3.48
	PE	pole	4	6	0.912	-7.90	-4.88
		cardboard	4	6	0.906	-19.27	-4.30
		animals	4	6	0.493	-8.11	-8.67
	PG+PE	pole	18	20	0.748	-9.58	-6.20
		cardboard	18	20	0.747	-20.67	-5.41
		animals	18	20	0.560	-1.56	-7.24

The evaluation of the different calibration methods for length calculation revealed that the method using *animals*' body length for calibration was the best method for adults (table R2). Coefficient of determination was highest and mean/standard deviation was lowest in this method. For the calibration methods *pole* and *cardboard* a continuous underestimation of animals' body length (mean deviations, and figure R2) was found. However, all calibration methods seemed to be equally precise in terms of standard deviation values. Here it had to be considered that the *pole* calibration was taken from elevation whereas the other two were taken from ground level. For adults body length calculation the calibration method *animals* was used for further calculations and evaluations.

For offspring length calculations two different methods had to be considered. The method using *animals*' body length for calibration had the best values for pictures taken from ground level, equally to the findings of adults (also table R2). For pictures taken from elevation the calibration method *pole* had the best values. In this picture type the method *animals* had a very low sample size for calibration/validation and distances were not equally distributed.

Calibrations for pictures in the picture types (*PG* and *PE*) had for both R^2 values above 0.7 and s.d. within 7 %. Using both picture types together for calibration changed the R^2 and deviation values remarkable for the worse. For further adult and offspring length calculations and evaluations the two calibrations for pictures taken from ground level and from elevation were separated.

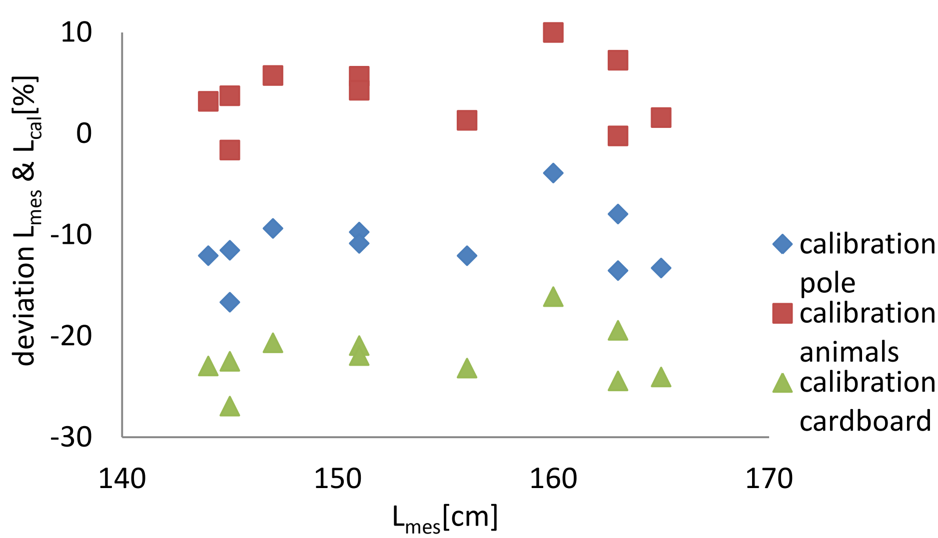


Figure R2 Comparison of different calibration methods for length calibration for adults and pictures taken from ground level.

3.1.2 Validation of the length calculations

a) Testing for errors in data acquisition

To evaluate how error-prone the photogrammetric method for length determination was, several parameters were tested while taking the pictures and clicking the contours of an animal within a pictures.

First, the impact of sidesteps of the person taking the picture and therefore a resulting deviation from the 90 degrees angle from the camera to the longitudinal axis of the object was checked. This deviation in the angle between camera and object correlated with the deviation of the measured to the calculated length (figure R3).

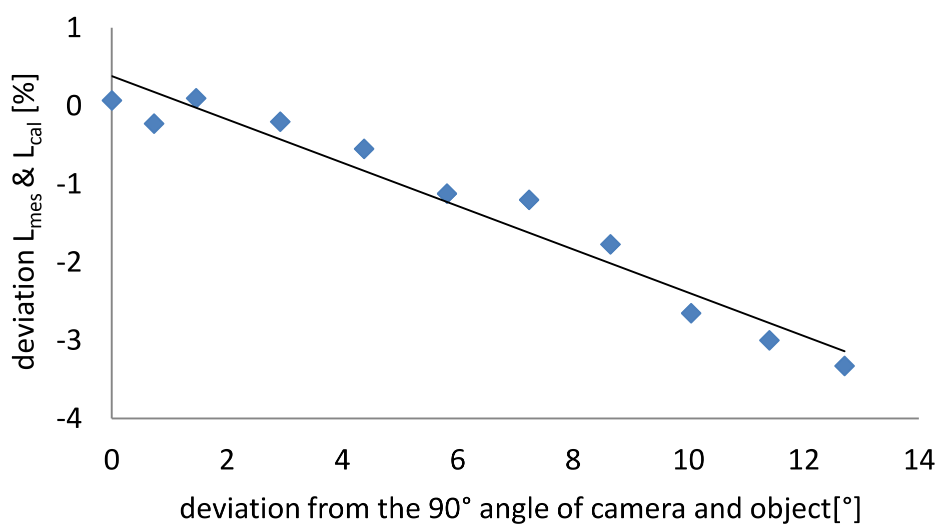


Figure R3 Impact of a deviation from the 90 degrees angle from the camera to the longitudinal axis of the object on the calculated length ($y = -0.2772x+0.3854$; $R^2 = 0.949$).

To check whether photographing an animal lying on sloped beaches had an impact of photogrammetric length calculations an object of known length was photographed in different positions. No impact of object rotation through the center of the object vertical to the image plan (s.d. = 0.33 cm) on length was found. The distance between camera and object had no impact on the calculated length (s.d. = 0.52 cm, $R^2 = 0.00001$).

The pictures were analyzed by the use of several Matlab programs. One part of this process was that the analyzer had to mark the contours of the object. It was checked for an impact of these marking on length calculation by repeating analyzes five times for ten pictures of an object of known length. The contour marking had almost no impact on the length calculation (figure R4, sd.≤0.21 cm).

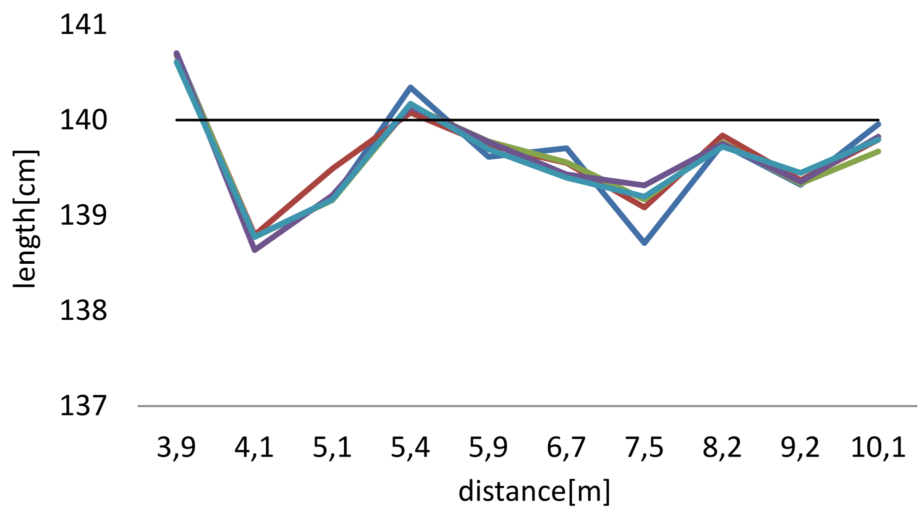


Figure R4 Influence of marking the contours of the object in the pictures on the calculated length over different distances. Each colored line represents one marking sequence and the black line represents the real cardboard length.

b) Evaluation of calculated animals' body length and parameters of pictures, animals and season

Adults

To derive a guideline for the use of photogrammetric length calculations pictures were categorized concerning certain parameters. The parameters were the picture type (*PG* and *PE*), the body form and position of the animal, assumed problems concerning the pictures and also the impact of a greater time span between taking the picture and capturing the animal (*season*). The impacts of these parameters on the quality of the calculated length are shown (table R3) using R^2 values and the mean/standard deviation from the measured and calculated length. For the *all picture analysis* neither R^2 values nor the standard deviations can be considered to be precise enough for length calculation (critical values: $R^2>0.7$, s.d.<5 %). These values can serve only for qualitative comparisons. Because of an overall small sample size and a high number of interactions of different parameters and problems within pictures were the results of the *all picture* analysis included.

After separation of the two picture types (separately excluding PG and PE) a positive impact on R^2 values could be found for each picture type.

The body form *good* (excluding body forms *bent*, *bad*), which was expected to be the best, had the best values compared to the other body forms. The worst values could be found for the body form *bent* (excluding body form *good*, *bad*) but there was a low sample size.

Excluding the *belly* position (body forms *good*, *bad*) caused slight improvements of values. It had to be considered that a lot of pictures with animals in the *belly* position appeared to have a lot of the defined problems. Regarding animals in the *back* position best values could be found but there were almost no problematic pictures included in this sample. Beside these findings there were no remarkable differences in position.

Excluding pictures of animals where the corresponding length measurement was done in the previous season (*season*) resulted in a slight improvement of the values.

Table R3 Evaluation of the accuracy and precision of calculated adult body length compared to measured body length and the impact of animals' positions and body form parameters in the picture, picture parameters and *season*. All pictures were used and evaluation of the impact of parameters on calculations was done by excluding parameters separately.

	factors excluded	n individuals	n pictures	R^2	$\bar{x}$ deviation L_{mes} & L_{cal} [%]	s.d. [%]
all		43	162	0.434	-2.85	8.15
picture type	PG	25	48	0.471	-4.64	8.31
	PE	31	114	0.457	-2.10	8.00
body form	bent	42	134	0.464	-1.89	7.99
	bad	43	140	0.426	-1.89	7.80
	bent, bad	40	112	0.485	-0.50	7.28
	good, bad	12	28	0.224	-7.44	7.41
position	belly	30	91	0.475	-2.87	8.62
	back	41	148	0.425	-3.13	8.29
	side	32	85	0.430	-2.35	7.36
	belly, back	27	77	0.470	-3.41	8.95
	belly, side	7	14	0.556	0.09	5.91
	back, side	27	71	0.409	-2.83	7.56
span picture-weighing	> one season	34	116	0.489	-2.60	8.04
problem	grass	42	153	0.441	-2.75	8.14
	head	41	127	0.399	-1.33	7.64
	another	35	119	0.414	-3.10	7.76
	all	30	86	0.410	-1.73	7.30

The *best picture analysis* was used for qualitative and quantitative evaluations of the calculated body length. *Best pictures* were defined as pictures taken from ground level, with an animal lying on the *belly* in a straight way (body form *good*) without any kind of problems. Also the picture taking and the weighing had to be done in the same season. Using only the *best pictures* for evaluating the impact of several parameters on the accuracy of adult body length calculations derived the highest values for R^2 and the lowest mean/standard deviation (table R4).

Length calculation including pictures taken from elevation had much lower R^2 values and slightly worse deviation values but also the lowest sample size. A difference compared to the method evaluation was that for the *best picture analysis* only the *belly* position pictures were used while for the method evaluation (table R2) all positions were used.

Including calculations with other body positions had almost no impact on the accuracy, measured in R^2 and deviation values, of the body length calculation. Including pictures with animals in *back* position even increased the R^2 value slightly whereas including pictures with animals in *side* position caused a slight misrepresentation of the length calculation.

Pictures in both picture types and with all three positions had a low R^2 value as well as pictures of all positions taken from elevation.

Including pictures of animals, where the corresponding length measurement was done in the previous season (*season*), slightly improved length calculations but only increased the sample size by two pictures.

The problems *grass* and *head* worsen the R^2 values drastically especially concerning the low number of problem pictures. Pictures with *another* problem had no negative impact on length calculations.

Table R4 Evaluation of the accuracy and precision of calculated adult body length compared to measured body length and the impact of animal position parameters in the picture, picture parameters and *season*. *Best pictures* were used and evaluation of the impact of parameters on calculations was done including or excluding parameters separately.

factors excluded	factors included	n individuals	n pictures	R^2	$\bar{x}$ deviation L_{mes} & L_{cal} [%]	s.d. [%]
		8	16	0.741	2.47	4.22
	PE	13	25	0.524	0.11	6.74
PG	PE	7	9	0.259	-4.09	8.49
	position back	8	17	0.754	2.23	4.20
	position side	10	22	0.716	2.05	4.01
	position back, side	10	23	0.731	1.89	3.99
	PE + position back, side	23	50	0.602	-0.02	5.65
PG	PE + position back, side	15	27	0.489	-1.65	6.38
	> one season	10	18	0.747	2.41	3.97
	problem grass	8	19	0.536	2.07	5.21
	problem head	9	18	0.620	1.66	4.65
	problem another	11	21	0.767	2.20	3.71

Selected parameters for length calculations additionally to *best pictures* were pictures in the position *back* and with *another* problem ($n = 22$, $R^2 = 0.777$, $\bar{x}$ deviation = 2.02, s.d. = 3.71). Pictures with animals in s*ide* position were despite good values (high R^2, low mean/standard deviation) excluded for further calculation. The whole model including category *side* position lowered the R^2 values enormous ($R^2 = 0.686$, $\bar{x}$ deviation = 2.99, s.d. = 4.89).

A GLMM for calculated and measured length was conducted to calculate the impact of position, sex and distance on the model and to test the model for significance (position was excluded $p>0.5$, sex $p = 0.03$, distance $p = 0.17$, length $p<0.001$). A significant difference in sex for calculating body length derived from pictures could be found (figure R5). But a low sample size for males ($n = 5$; female $n = 17$) has to be noticed.

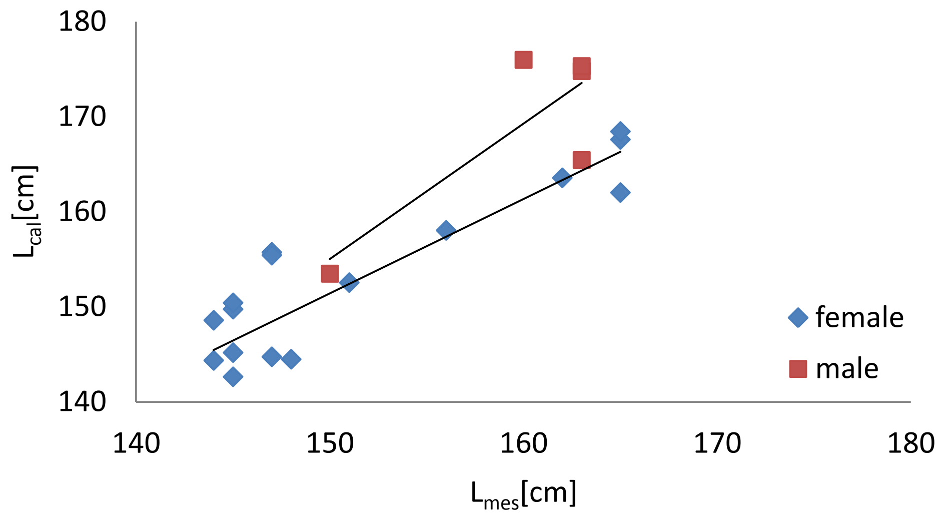


Figure R5 Sex differences of the calculated and measured length of adults (female y = 0.9921x+2.6068, R^2 = 0.767; male y = 1.4258x-58.84, R^2 = 0.686).

Offspring

The evaluation of length calculations for offspring (table R5) showed almost the same results in the *all picture analysis* as for adults (table R3) except the finding for the body form *bent*. The qualitative differences in R^2 values and mean/standard deviation were clearer than for adults. Additionally in offspring was the amount of problem pictures and parameter interactions lower because pictures of offspring were always taken on the beach.

Pictures with animals in body form *good* had very high R^2 and low mean/standard deviation values for this type of analysis. Offspring pictures with animals in the body form *good* had a low amount of pictures with the defined problems. The body form *bad* had a negative impact on the accuracy of length calculation. Surprisingly high R^2 values could be found for *bent* animals. But there was an underestimation and a high standard deviation.

Animals' body positions *belly* and *back* influenced the calculations positively but position *side* worsened the R^2 values and the s.d. immensely. This supported the findings in adults.

Excluding all problem pictures increased the R^2 values and revised the deviation values.

Table R5 Evaluation of the accuracy and precision of calculated offspring body length compared to measured body length and the impact of animals' body form and position parameters in the picture, picture parameters and *season*. All pictures were used and evaluation of the impact of parameters on calculations was done by excluding parameters separately.

	factors excluded	n individuals	n pictures	R^2	$\bar{x}$ deviation L_{mes} & L_{cal} [%]	s.d. [%]
all		52	96	0.315	-3.84	9.81
picture type	PG	10	18	0.392	-7.09	15.09
	PE	43	78	0.405	-3.09	8.09
body form	bent	40	73	0.324	-1.67	8.42
	bad	49	82	0.431	-3.74	9.41
	bent, bad	37	59	0.494	-1.01	7.20
	good, bent	12	14	0.057	-4.45	12.29
	good, bad	14	23	0.634	-10.74	10.88
position	belly	32	64	0.211	-3.48	10.77
	back	48	84	0.273	-4.48	9.90
	side	28	44	0.550	-3.16	8.03
	belly, back	27	52	0.089	-4.42	11.14
	belly, side	7	12	0.564	0.60	8.16
	back, side	22	32	0.739	-4.57	7.64
span picture-weighing	>one season	46	88	0.365	-3.35	8.34
problem	another	49	81	0.283	-4.21	10.26
	head	45	76	0.283	-2.86	9.06
	all problems	40	60	0.405	-2.46	8.18

For offspring in the *best picture analysis*, the impact of different parameter on length calculation (table R6) derived the same outcome than for adults (table R4). Additionally it could be shown that animals lying in a *bent* body form might be considered for length calculation. Measured and calculated lengths correlated very well and had a low standard deviation value but there is a constant underestimation of the body length. Also this was based on a low sample size.

Table R6 Evaluation of the accuracy and precision of calculated offspring body length compared to measured body length and the impact of animals' body form and position parameters in the picture and picture parameters. *Best pictures* were used and evaluation of the impact of parameters on calculations was done including or excluding parameters separately.

factors excluded	factors included	n individuals	n pictures	R^2	$\bar{x}$ deviation L_{mes} & L_{cal} [%]	s.d. [%]
		7	8	0.577	-0.24	6.52
	PE	12	14	0.559	-1.27	9.22
PG	PE	5	6	0.314	-2.65	12.55
	position back	9	10	0.697	-0.34	5.80
	position side	21	27	0.560	-0.88	4.97
	position back, side	22	29	0.633	-0.87	4.81
position belly	position side	14	19	0.596	-1.14	4.35
	lying bent	12	16	0.696	-3.99	6.63
	PE + position back, side	28	40	0.446	-0.94	6.65
PG	PE + position back, side	7	11	0.246	-1.15	10.37
lying good	lying bent	5	8	0.875	-7.74	4.43

Additionally to *best pictures* only *back* pictures were selected to be precise enough for offspring body length calculation (n = 10, R^2 = 0.697, $\bar{x}$ deviation = -0.34, s.d. = 5.80). The model for L_{cal} and L_{mes} was highly significant (GLMM, $p<0.01$) and there was no impact of distance and sex (distance p = 0.96, sex p = 0.95). Other than for adults no differences in sex for body length calculations could be found for offspring (appendix figure A19).

3.2 Results mass measurements

There was an impact of animals' age found on mass calculations using a two dimensional photogrammetric method (GLMM, $p<0.0001$). The following mass calculations were therefore separated for adults and offspring.

3.2.1 Calibration for area and body mass

a) Deriving the calibration methods

For mass calibration and evaluation the same analyses were conducted as for length.

Three different calibration approaches (*pole*, *cardboard*, *animals*) were used for animals' body mass calculations. The calibration equations were derived by plotting the parameter in the equation (area or mass/ number of pixel within the animal`s body over distance) and converting this straight line equation (table R7). For the calibration methods *pole* and *cardboard*, first the side area of the animal in the picture was calculated. For calculating animals' body mass, half of the pictures were chosen for calculated side area and measured mass correlations. The derived line equation was converted and used for mass calculations. For the calibration method *animals*, mass divided by the number of pixels of the area was directly plotted over distance. Therefore the converted equation could be directly used for photogrammetric body mass calculations.

Table R7 Summary of the equations for mass calculations for different calibration methods.

	methods	equation	R^2
adult	pole (n = 8)	area[cm²] = ((0.0139*distance-0.0016)^2)*$pixel_{area}$	
		M_{cal}[kg] = 0.0204*area^1.0448	0.877
	cardboard (n = 8)	area[cm²] = pixelarea/(5259.6*distance^-1.991)	0.999
		M_{cal}[kg] = 0.0176*area^1.0619	0.849
	animals (n = 8)	M_{cal}[kg] = (0.000005*distance^2.0785)*$pixel_{area}$	0.993
	animals PE belly, back (n = 8)	M_{cal}[kg] = (0.00005*distance-0.0001)*$pixel_{area}$	0.867
	animals belly, back, side(n = 12)	M_{cal}[kg] = (0.00007*distance-0.0002)*$pixel_{area}$	0.990
offspring	pole (n = 4)	Area[cm²] = ((0.0139*distance-0.0016)^2)*$pixel_{area}$	
		M_{cal}[kg] = 0.0661*area^0.8357	0.895
	cardboard (n = 4)	Area[cm²] = pixelarea/(5259.6*distance^-1.991)	0.999
		M_{cal}[kg] = 0.0357*area^0.9186	0.909
	animals (n = 4)	M_{cal}[kg] = (0.000004*distance^1.9092)*$pixel_{area}$	0.992
	animals side (n = 10)	M_{cal}[kg] = (0.000003*distance^2.2925)*$pixel_{area}$	0.964

All calibration curves were highly correlated but the best coefficient of determination was calculated for the calibration method *animals*. This was based on a low sample size especially in offspring.

b) Influence of calibration methods on photogrammetric body mass calculations

The accuracy and precision of the three different calibration methods for mass calculations was evaluated. Therefore every picture was separately analyzed for every method and accuracy and precision was compared (table R8).

Table R8 Evaluation of the accuracy and precision of the three different calibration methods and different picture types (*PG* and *PE*) of the photogrammetrically calculated body mass. Only the body position *belly* is used for calibration and validation.

age	parameter	calibration method	n individuals	n pictures	R^2	$\bar{x}$ deviation M_{mes}&M_{cal} [%]	s.d. [%]
adult	belly	pole	5	7	0.937	-3.24	-7.13
		cardboard	5	7	0.923	-2.39	-7.57
		animals	5	7	0.945	2.88	-6.70
	belly,back,side	animals	6	11	0.670	1.19	12.77
	PE,belly,back	animals	7	8	0.179	34.28	23.20
offspring	belly	pole	3	4	0.691	5.31	-3.04
		cardboard	3	4	0.572	5.80	-3.45
		animals	3	4	0.507	0.40	-3.91
	side	animals	7	9	0.883	7.18	8.38

The comparison of the methods for mass calculation showed the best results for adults with the calibration method *animals*. Additionally included pictures with all positions or taken from elevation worsen the R^2 and mean/standard deviation values.

There was a very low sample size for offspring in *belly* position. The best R^2 value was achieved with the calibration method *pole* and the best mean deviation value was achieved with the calibration method *animals*. The calibration for *side* position had a high correlation value between measured and calculated mass but a slight overestimation occurred.

In figure R6 the deviations for measured and calculated mass were plotted. Until 70 kg the calibration method *animals* derived the lowest deviation of M_{cal} and M_{mes}. For measured body masses over 70 kg this method seemed worst and the calibration *pole* was most precise.

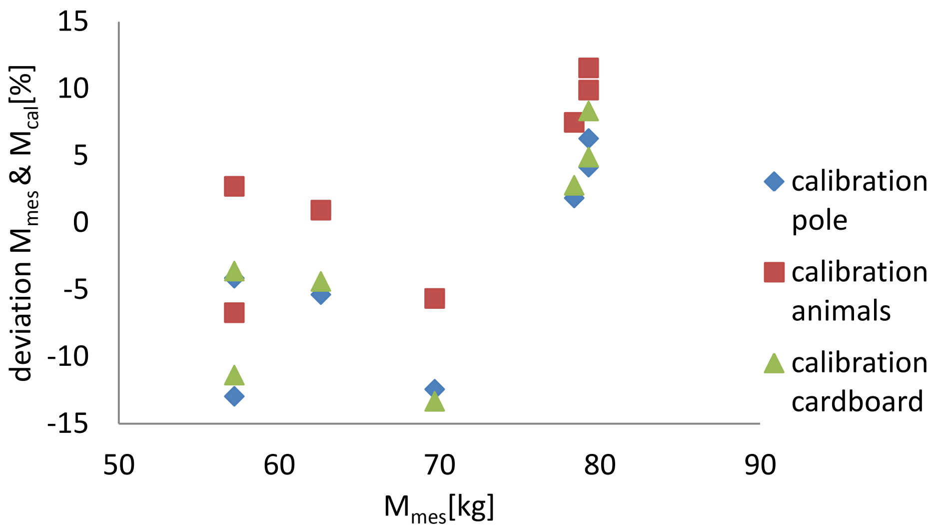


Figure R6 Comparison of the different calibration methods for mass calculation for adult and position *belly*.

3.2.2 Validation of the area and mass calculations

a) Testing for errors in data acquisition

Errors in photogrammetrically calculating the area/ mass can be generated while taking and analyzing the pictures. This was tested while taking several pictures of an object of known area, the cardboard. It could be shown that the angle (figure R7) and the distance (figure R8) between object and camera had an impact on the calculated area. There was no impact of object rotation through the object center vertical to the image plan on the calculated area (object area = 3500 cm², s.d.$_{cal}$ = 32.52 cm²).

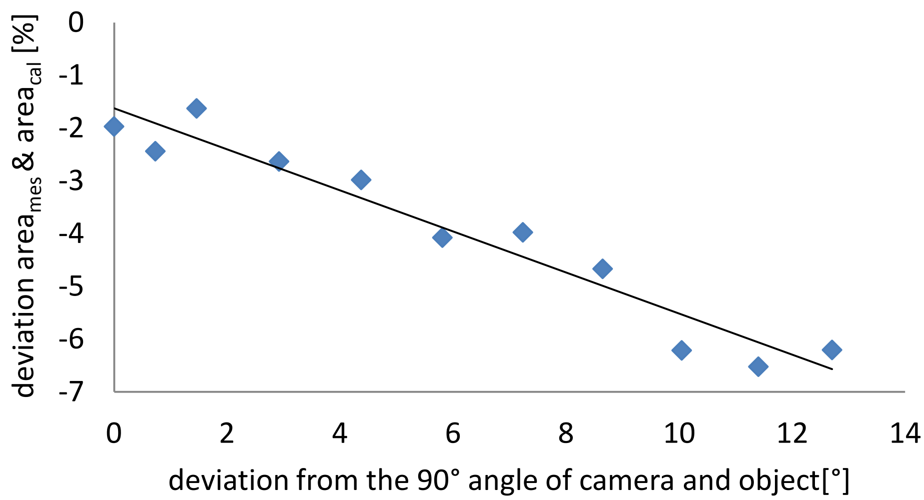


Figure R7 Impact of a deviation from the 90 degrees angle from the camera to the longitudinal axis of the object on the calculated area ($y = -0.389x-1.6249$; $R^2 = 0.936$).

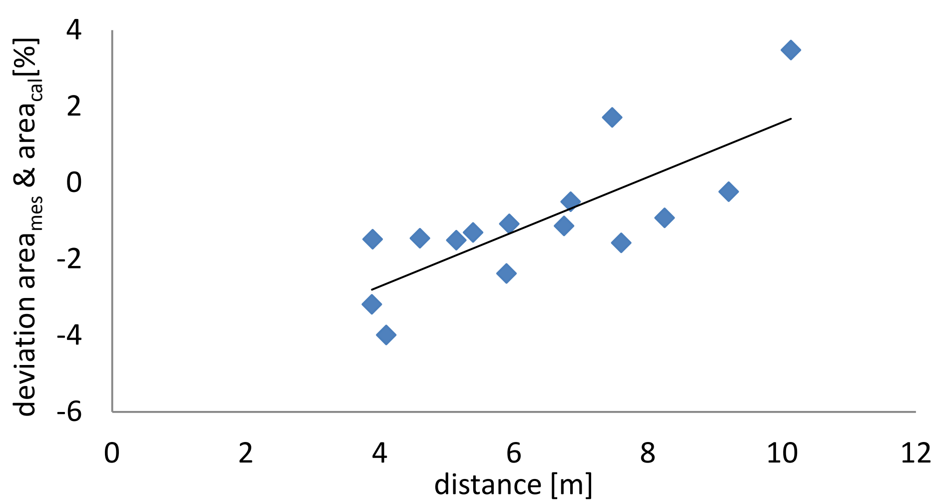


Figure R8 Influence of the distance between camera and object on the calculated area ($y = -0.7152x-5.5717$; $R^2 = 0.596$).

During the analyzing process of the pictures the analyzer had to mark the contours of the object and could possibly have a negative impact on area/ mass calculations. This was tested by repeated analyses (five times) of ten pictures and comparison of the results. It could be shown that the clicking procedure had no impact on the calculated area (figure R9, s.d.≤43.74). Interestingly more overestimation occurred with very low and very high distances.

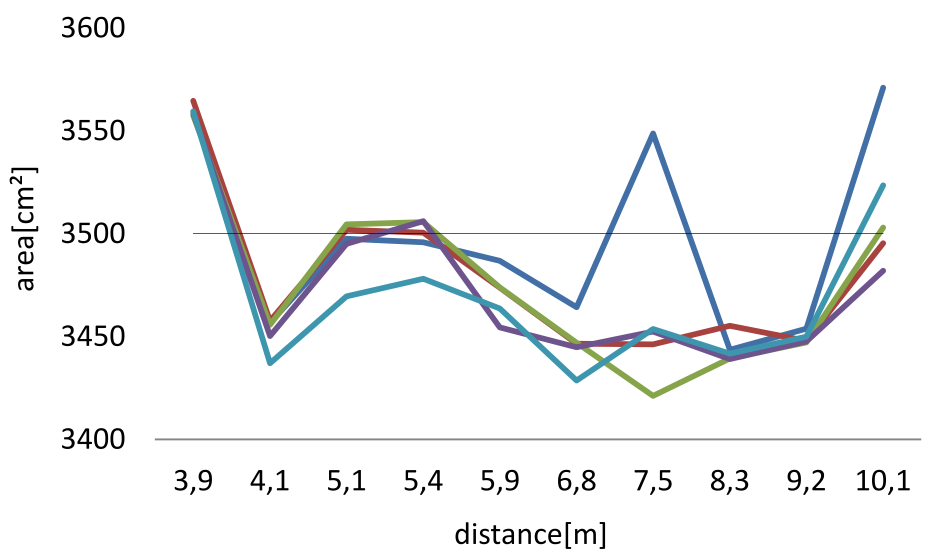


Figure R9 Influence of marking the contours of the object in the pictures on the calculated area over different distances. Each colored line represents one marking sequence and the black line represents the real cardboard area.

b) Evaluation of calculated animals' body mass and parameters of pictures, animals and season

Adults

One aim of this study was to derive a guideline for photogrammetrically estimating the body mass of sea lions. Therefore several factors, which could have an impact on mass calculation, were categorized and evaluated. For evaluating the impact of different animal and picture parameters on the photogrammetric body mass calculation, accuracy as a measure of high coefficient of determination and low standard deviation values and precision as a measure of low mean deviation values were calculated.

No additional information could be derived from the *all picture analysis* of adults. Only the more precise *best picture analysis* was used for the evaluation of adult mass calculations.

Calculated and measured adult body mass for the *best pictures* were highly correlated and had low mean and standard deviations (table R9).

Including pictures taken from elevation or looking at the picture types (*PG*, *PE*) separately had a negative impact on mass calibration. Calculating and using a calibration for elevated pictures did not change the negative impact on mass calculation.

Only one position *back* picture could be included but this seemed to have no impact on R^2 or deviation values. Remarkably worse results could be found when including pictures with animals lying on the *side*. Considering pictures of the category *side* separately (excluding position *belly* and *back*) did not change the fact.

If the corresponding weighing took place in the previous season compared to taking the picture (*season*), a negative impact on the mass calculation could be shown. However, this conclusion is based on two pictures only.

Pictures in the category problem had very low sample sizes (*grass* problem n = 3, *head* problem n = 2, *another* problem n = 5). Including *grass* problem pictures had an immensely negative influence and *head* problem pictures seemed to have a low negative impact on calculation. Including *another* problem pictures derived almost the same values as the *best pictures* itself.

Table R9 Evaluation of the accuracy and precision of calculated adult body mass compared to measured body mass and the impact of animals' position parameters in the picture, picture parameters and *season*. *Best pictures* were used and evaluation of the impact of parameters on calculations was done including or excluding parameters separately.

factors excluded	factors included	n individuals	n pictures	R^2	$\bar{x}$ deviation M_{mes}&M_{cal} [%]	s.d. [%]
		8	16	0.875	4.54	6.22
	PE	13	25	0.478	10.49	16.06
PG	PE	7	9	0.306	21.07	22.46
	position back	8	17	0.873	4.71	6.07
	position side	10	22	0.745	3.50	7.45
	position back, side	10	23	0.745	3.67	7.33
position belly	position side	3	6	0.491	0.73	10.22
	season	10	18	0.796	3.59	6.73
	grass problem	8	19	0.386	4.37	13.87
	head problem	9	18	0.833	3.55	6.52
	another problem	10	21	0.867	5.17	6.40
	PE position back, side	23	50	0.491	14.92	16.43
PG	PE position back, side	15	27	0.502	24.50	15.99
		calibration PE				
PG	PE position back	11	16	0.301	34.24	22.33

Selected parameters to be included in adult mass calculation were *best pictures*, pictures with *another* problem and with animals in position *back* (n = 22, R^2 = 0.867, $\bar{x}$ deviation = 5.29, s.d. = 6.26). There was no impact of position, distance or sex on the correlation between measured and calculated mass (GLMM; excluded: position p = 0.668, distance p = 0.864, sex p = 0.893). But just five out of 22 animals were males and there was a limitation in capturing bigger animals. The model concerning the correlation of measured and calculated mass was highly significant ($p<0.0001$).

Offspring

Evaluation of mass calculation for offspring in the *all pictures analysis* could be used only for qualitative comparisons (table R10). In this analyzing method the accuracy and precision values of all pictures were compared with the values of all pictures excluding individual animal or picture parameter.

An impact of the height of the camera while taking the pictures could be found. Excluding pictures taken from ground level increased R^2 values but worsened the deviation values immensely.

Animals body forms *good* and *bent* had a positive effect on offspring mass calculation whereas body form *bad* had a very negative effect on accuracy and precision values.

Higher R^2 values and lower deviation values could be found in the positions *belly* and *back* but the opposite was found for the *side* position.

Table R10 Evaluation of the accuracy and precision of calculated offspring body mass compared to measured body mass and the impact of animals' body form and position parameters in the picture, picture parameters and *season*. All pictures were used and evaluation of the impact of parameters on calculations was done by excluding parameters separately.

	factors excluded	n individuals	n pictures	R^2	$\bar{x}$ deviation M_{mes}&M_{cal} [%]	s.d. [%]
all		54	99	0.501	-0.06	18.62
picture type	PG	10	18	0.815	18.76	20.96
	PE	45	81	0.487	-4.24	15.29
body form	bent	42	76	0.482	1.12	18.98
	bad	51	85	0.665	-0.70	16.90
	bent, bad	39	62	0.735	0.51	16.77
	good, bad	14	23	0.664	-3.95	17.18
	good, bent	12	14	0.028	3.81	27.37
position	belly	34	67	0.340	-1.55	20.06
	back	50	87	0.449	0.52	19.35
	side	28	44	0.781	1.07	14.41
	belly, back	29	55	0.215	-0.97	21.49
	belly, side	7	12	0.763	-4.25	11.77
	back, side	22	32	0.788	3.06	14.96
span picture-weighing	season	46	88	0.469	-1.18	18.99
problem	head	47	79	0.481	-0.84	17.56
	another	50	82	0.486	1.24	19.59
	all	41	61	0.463	0.52	18.81

The *best picture analysis* could be used for qualitative and quantitative evaluations of the calculated body mass. Photogrammetric mass calculation for offspring derived high accuracy for the *best pictures* (table R11). All parameters included individually had very high correlation values but differed enormously in deviation values.

Including the pictures taken from elevation had a negative impact on mass calculation, especially on the standard deviation. This did not change while including more positions.

Including additional pictures of other body forms or positions in analysis decreased the standard deviation and could not be considered for further calculations. However, the photogrammetrically calculated body mass was only a little less accurate and precise if the body form *bent* and the position *side* were included.

Table R11 Evaluation of the accuracy and precision of calculated offspring body mass compared to measured body mass and the impact of animals' body from and position parameters in the picture, picture parameters. *Best pictures* were used and evaluation of the impact of parameters on calculations was done including or excluding parameters separately.

factors excluded	factors included	n individuals	n pictures	R^2	$\bar{x}$ deviation M_{mes}&M_{cal} [%]	s.d. [%]
		7	8	0.881	-2.78	5.96
PG	PE	5	6	0.827	21.95	9.81
	PE	12	14	0.885	7.82	14.74
	lying bent	12	16	0.912	-5.45	8.41
	position back	9	10	0.831	-4.40	10.02
	position side	21	27	0.864	-4.16	8.02
	position back, side	22	29	0.866	-4.62	9.07
	PE position back, side	28	40	0.758	1.62	18.20
position belly	position side	14	19	0.866	-4.74	8.82
lying good	lying bent	5	8	0.896	-8.12	9.98
PG	PE position back, side	7	11	0.818	18.06	25.52

There were no additional parameters selected for the body mass calculation of offspring (values for *best picture*s see table above). There was no significant impact of sex ($p = 0.229$) on calculation and distance could not be included due to a low sample size. The correlation for calculated and measured mass was highly significant ($p = 0.0025$).

3.3 Application to body condition

Another aim of this thesis was to calculate body length and body mass precise enough for the use in body condition studies. A comparison between measured and calculated animal body condition was done for adults (figure R10). The calculated residuals agreed in sign in ten out of 15 cases. A paired student's t-test of the calculated and measured residuals indicated that the values are not significantly different from each other (p-value = 0.9991).

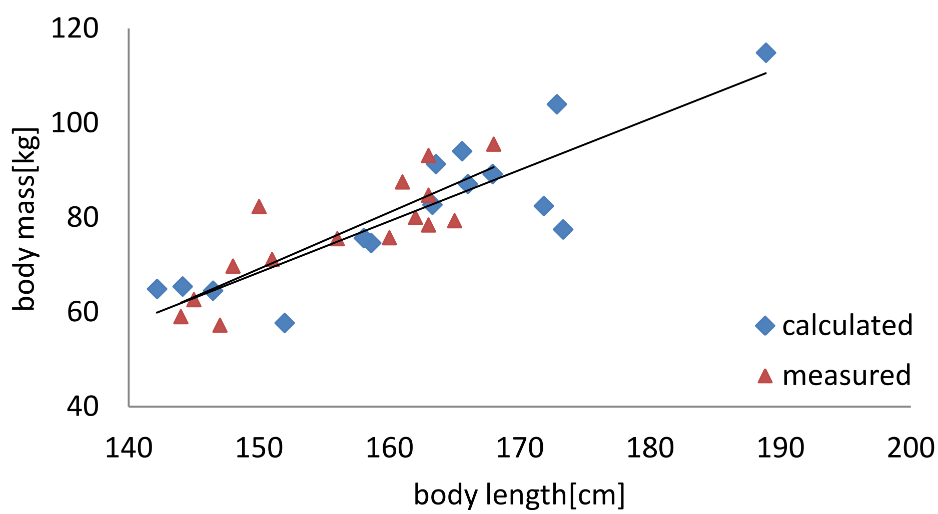


Figure R10 Comparison of measured and calculated correlations of length and mass (measured $y = 1.1927x-109.77$, $R^2 = 0.713$; calculated $y = 1.0839x-94.244$, $R^2 = 0.754$).

4. Discussion

The first chapter of the discussion evaluates the general accuracy of photogrammetric body length and mass calculation derived in the present study. The following parts consider the impact of the calibration methods, the impact of factors while taking the pictures and factors concerning the pictures itself on the calculations. Finally the application of the photogrammetric method in order to evaluate body condition is discussed.

4.1 General evaluation of the accuracy of photogrammetric measurements

The evaluation of the presented photogrammetric body length and mass determination in adult Galápagos sea lion showed very high accuracy and precision. Almost no visible disturbance of the animals could be noticed while taking the pictures (personal experience) and only a few animals had to be captured for calibration and correlations. These low influences decrease the stress for the animals and enable a single researcher to collect a large data set. Therefore, this photogrammetric method provides a very good way of measuring the body length and mass of Galápagos sea lion.

For offspring the overall sample size of pictures taken in the present study was lower than for adults. Therefore the distribution of distance data for calibration was more critical. However, the photogrammetric body length and body mass calculation derived high accuracy and precision and can be used instead of capturing and manually measuring the body parameters of offspring. The benefit of this photogrammetric method is less pronounced for offspring than for adults since it is easier to capture offspring. However, the reduced need for equipment and the reduced number of people needed for photogrammetrically measuring body length and mass is a great advantage of this method, even for measuring the body parameters of offspring.

In comparison to literature (see introduction) the accuracy of the photogrammetrically calculated body length values in the present study are the best known values. Calculated body mass values in the present study (range 95 % of CI, adults: 2.67 to 7.91, offspring: -1.34 to -6.91) are very close to the best values found in literature of photogrammetrics of pinnipeds. However, the study with the highest accuracy of photogrammetrically calculating the body mass (de Bruyn et al. 2009) describes a method which cannot be used for studying the body parameters of wild sea lions. Photogrammetrically measuring the body parameter of wild animals is successfully done with two dimensional methods. Best values of a two dimensional photogrammetric body mass study of wild pinnipeds range from ±5 to 9 kg (95 % of CI, McFadden 2006) in offspring Hawaiian monk seals with a body mass ranging from 10-120 kg (deviation 4.2-50 % , 95 % of CI). Compared to this, the present study provided the most accurate and precise photogrammetrically calculated body mass values.

A major factor improving the photogrammetric method compared to other studies was probably the use of a range finder instead of a scaling pole for scaling the pixel within the picture. This decreased the error while taking the picture and enabled the use of a calibration with the animals itself. Also this study compared and evaluated several factors influencing the quality of photogrammetric calculations. Only the best and most comparable pictures of Galápagos sea lions were selected and therefore a highly accurate and precise way of photogrammetrically calculating animals' body length and mass was provided.

The accuracy of repeated manual body length measurement of captive sea lions by several persons (Waite et al. 2007) was slightly better than the photogrammetrically calculated body length in adults. In the present study the length of adult sea lions could be precisely calculated photogrammetrically within 9.5 cm deviation (on average 2.9 to 3.3 cm). Manually repeated measurements of the same individual sea lion derived deviations up to 6.5 cm (approximate body length 100 -200 cm, Waite et al. 2007). On average, the photogrammetric method has lower deviations than the manual measurements but tends to be worse in the outer ranges. This is a good argument for the use of this photogrammetric length measurement and should lead to a preference of photogrammertic measurements over manual measurements.

For manual mass measurements less impact of the person weighing the animal was expected but no proof for this proposition can be found in literature. However, there are factors which should have a higher influence on body mass than on body length measurements. Those could be the difference of wet and dry animals and movement of the animal while weighing. In the present study the deviation of the photogrammetrically calculated and measured body mass was within 11.55 % (mean + standard deviation). This value seems quite high, but considering that there are several factors influencing the manual weighing this is reasonable. The corresponding mean deviation was 5.29 % (3.0-4.2 kg). This is accurate enough for a lot of different studies concerning the body mass of adult sea lions.

The accuracy of this method can be further increased with a separation of the calculations for adult males and females. Since there is sexual dimorphism, there could be a difference in photogrammetrically calculating body length and mass of male and female sea lions. In the present study there was a sex difference for photogrammetrical calculations of the body length. Calculations of females' body length derived slight underestimation whereas males' body length was always overestimated (figure R5). This difference could have been generated because of the use of the same calibration equation for the sexes. For photogrammetric body mass calculations no difference in sex was found but should be expected due to sexual dimorphism. One drawback of this study was the low sample size in some categories. For comparison of male and female calculation only two male individuals were weighed and three individual males were used for length measurement. This could influence the findings of sex differences. Regarding figure A20 (appendix) it is obvious that the distribution and low sample size of male mass data made it impossible to detect sex differences for photogrammetric body mass calculations. Additionally, the individual males and females captured were almost of the same sizes and masses (mean length: males = 160 cm, females = 151 cm; mean mass: males = 78 kg, females = 67 kg). This was because it is very difficult to capture the biggest individuals. Since there is sexual size dimorphism it is most likely that the bigger individuals are males. Capturing those bigger males could help clarifying the question of sexual differences in photogrammetric calculations. For finally answering the question of difference in sexes while photogrammetrically calculating the body mass the sample size of captured males was too low in the present study. Nevertheless, the results indicate that there is a difference in sex while photogrammetrically calculating animals' body length. For future studies it would be beneficial capturing adult animals of the whole range of sizes in both sexes and again comparing the photogrammetric calculations for males and females.

A significant sex difference in offspring mass is found in the California sea lion (Ono et al. 1987, Ono and Boness 1996). There males were significant heavier than females (on average 2.5 to 3 kg). Despite that fact no difference in photogrammetrically calculating offspring`s body length and mass has been found in the present study. The differences of male and female body parameters in offspring might be very small and not detectable with photogrammetric body calculations. In the present study the accuracy of the photogrammetrically calculated offspring body mass was within 2.5 kg. The male offspring captured in the present study were on average 1.3 kg lighter than the females. Obviously this method was not precise enough to detect this difference in offspring. The same pattern can be observed for offspring body length calculations: Females are on average 2.8 cm longer but the accuracy of the photogrammetrically estimated body length was within 6.9 cm. Therefore differences in calculating body parameters of different sexes could not be detected in offspring. The reverse differences in the measured parameters of offspring in the present study and in the study of Ono et al. (1987) are due to the procedures of the studies. In the present study, offspring ranging in age up to six months were captured, whereas Ono et al. studied offspring of one week of age. It could be that in the present study captured female offspring were older than male pups. This would highly influence the results in differences of sex since offspring growth rate can range up to 0.15 kg per day in sea lions (Ono et al. 1987). Overall, concerning sex difference in offspring sea lions, the method of photogrammetrically estimating body parameters is not accurate enough. However, this method can still be useful for studies of offspring parameters since data acquisition is simplified and the accuracy of this method is sufficient for a lot of different further studies concerning body length and mass of offspring Galápagos sea lion.

4.2 Evaluation of calibration methods

4.2.1 Body length

The best fit for calculating the body length of sea lions should be achieved using a calibration with the same object, meaning the animal itself, which could be observed for the calibration method *animals* (best values for accuracy and precision).

The worst deviation values were found for the body length calculations if the calibration *cardboard* was used. There the highest aberrations existed between shape and the surrounding of the cardboard used for calibration and the animal which body length was going to be calculated. A rectangular and flat piece of cardboard was photographed indoor in artificial light. Neither the shape nor the surrounding of the animal was considered. Also the distance between camera and cardboard could be influenced due to different shapes of the objects. The distance should be more variable if animals are photographed due to the cone form of the animal. If the laser slightly shifts in position up or down the distances between animal and camera could vary a lot. For the cardboard a shift of the laser position should not have any impact on the distance. Therefore, the impact of the form of the animal on distance measurements was not considered in the calibration method *cardboard*. These could explain the high error of this method.

The pole, used in the calibration method *pole*, is a cylindrical solid figure which was photographed in the same environment in which the sea lions live. In this method the discrepancy of the parameter of the method and the actual surrounding was lower than in the method *cardboard*. The order of the accuracy values of the methods *pole* and *cardboard* were as expected: calibration method *pole* was better than *cardboard*.

However, since there was a constant underestimation and a high accuracy while using the calibration methods *pole* and *cardboard* it might be possible to use them for body length calculations. For this a constant value could be determined and added to the calculated body length. Using the calibration methods *pole* and *cardboard* for photogrammetric length calculations can be beneficial when capturing the animals for calibration is difficult. Also this method could be applied in studies if only differences between animals length are going to be analyzed and the actual size is not important.

For selection of a calibration method the picture type (*PG*, *PE*) had almost no impact. For pictures taken from ground level (*PG*) the calibration method *animals* was used as explained above for adults and offspring. Selecting a calibration method for pictures taken from elevation (*PE*) was more complex. For this picture type two different suggestions were made: On one hand, the highest accuracy could be achieved with the calibration method having the best fit for object shape and surrounding which would be the method *animals*. On the other hand, the highest accuracy could be achieved with the calibration method having the pictures taken from the same height for calibration and for calculation (method *pole*). For pictures of adults taken from elevation the calibration method *animals* derived the best values. A higher impact of equal shape and surrounding can be concluded. For offspring a different pattern was found. There the calibration method pole derived the best body length calculations. This pattern can be explained by looking at the sample size of the calibration method *animals* for offspring. Only four animals were used for calibration and additionally these values were not equally distributed over different distances (same pattern as for *PG*, see figure R1). Therefore it is not surprising that the equation derived from the calibration method *animals* could not be used to calculate accurate body lengths for offspring in the picture type *PE*. There the method *pole,* with the same heights while taking the pictures for calibration and calculation (*PE*), derived the most accurate body length calculations.

If both picture types are calibrated and analyzed together body length is calculated with the lowest accuracy and precision. Therefore if both picture types are used for photogrammetric studies of sea lions the calibrations and calculations should be separated.

The calibration method *pole* is the most reliable one, because sample size and distribution of samples over distances can be influenced by the researcher. If the sample size drops or the deviation of distance values is unequally distributed the calibration method *pole* should be used for photogrammetric body length calculations.

Overall, the method *animals* is the most accurate calibration method because it is conducted with the same body shape and surrounding than the animal itself.

4.2.2 Body mass

In the calibration method *animals* the animals' body mass was directly used for calibration and the resulting straight line equation was converted for photogrammetric body mass calculations. For the calibration methods *pole* and *cardboard* the side area of the animal in the picture was calculated and correlated to the measured body mass. The calibration method *animals* required fewer steps for calibration and calculations. Additionally in the method *animals* the body shape and the surrounding were considered, since the object (animal) was the same for calibration and calculations. This method can be used to calculate the body mass of sea lions with higher accuracy than with the other two methods for calibration (*pole* and *cardboard*). This finding was not differing between age classes (adults, offspring).

The differences in accuracy of the three calibration methods while photogrammetrically calculating animals' body mass decreased with calculations of animals over 70 kg (figure R6). There the errors of measured body mass for the three calibration methods were more similar to each other. This was due to the quadratic form of the calibration functions. However, this does not explain why for calculations above 70 kg the calibration method *animals* delivered slightly higher deviation values than the calibration methods *pole* and *cardboard*. It might be that the sample size for calibration was too low to calculate an accurate equation for photogrammetric body mass calculation especially for animals over 70 kg. In this analysis only a sample size of two individuals over 70 kg was considered. In this case the calibration methods *pole* and *cardboard* might be more reliable. There the amount of calibration values can be controlled by the researcher and side area can be calculated independent of the animals' body mass. This indicates that these methods are less prone for low sample sizes or unequal distributions of calibration values. To understand the mechanism of photogrammetrically calculating the body mass of heavier sea lions (>70 kg) the sample size needs to be increased in further studies.

If pictures with animals in other positions (*side*, *back*) were included for body mass calibrations, the accuracy of photogrammetric body mass calculations was worse. The side area of an animal changed drastically while lying in different positions. If an individual is photographed from the side, the area was larger than the area of animals photographed while lying on the belly or the back. This made a comparison between pictures difficult. Therefore only animals photographed in the position *belly* are considered for body mass calibrations in adult and offspring Galápagos sea lions.

The body mass calculations were also drastically worse if pictures of the picture type *PE* were included for calibration. If pictures were taken from elevation, the point of view on animal's side area changed with the distance between camera and animal. If the distance increased the point of view of the photographer on the animals side area shifted towards the top area. This problem did not occur with pictures taken in the picture type *PG*. Therefore photogrammetric body mass calculations are most accurate and precise if only pictures are used which are taken from *ground level*.

The highest accuracy and precision in photogrammetrically calculating the body mass of the Galápagos sea lion was achieved with the calibration method *animals*. This calibration should be preferred in further studies if the sample size and the distribution of data for calibration are sufficient. No additional picture parameter (picture type *PE*) or parameter of animals in the picture (positions *back* and *side*) should be selected for calibration.

4.3 Factors influencing the accuracy of the photogrammetric method

4.3.1 Testing for errors in data acquisition (length and area)

While taking the picture the camera should be in a 90° angle to the longitudinal axis of the animal (Figure M1). Since there are a lot of interfering factors (other animals, stones and bumps in the underground) while taking the picture and only the human sense of vision is used to achieve this 90° angle it can be difficult for the photographer to take a picture from exactly that angle. It was expected that a deviation in this angle changes the view on the object in the picture and leads to underestimation for length and area calculation. Indeed negative correlations between change in object angle and deviation of photogrammetrically calculated and manually measured length (R^2 = 0.949) and area (R^2 = 0.936) were found. The impact of a shift in angle was more pronounced for area than for length calculations. This is results from a higher number of pixels affected by the angle change on area calculations.
In order to minimize the error due to angle changes it is necessary that the photographer pays attention to the angle. During the field experiments it arose, that this is accomplishable best while taking pictures from the ground level. An angle change was also visible in the pictures itself. For a researcher it is easy to control this factor by paying attention to the angle when taking the picture and by filtering the pictures afterwards.

In the wild Galápagos sea lions often lie on slope beaches. This changes the angle of the animal's horizontal center line to the horizontal center line of the picture. This could have had an impact on photogrammetrically calculating morphometrics of the animals. No impact of a change of object angle, neither for calculating object length nor for calculating object area, was noticed. Thus, for photogrammetrics a change in the angle of the object is negligible.

Additionally the impact of a change in distance between object and camera was considered. Especially if the object was photographed very close (around 4 m with an object of 140 cm) the deviation between manually measured and photogrammetrically calculated area was higher than the average deviation values (figure R8). In this case the object filled out almost the whole picture in length. Therefore the distortion of the lens could have a higher impact on the animal in the picture than if the animal in the picture fitted in just half of the picture. For pictures taken in distances above four meter the deviation values between measured and calculated parameters decreased.

For object area calculations the error of the photogrammetric method increased again for high distances (10 m). If the distance between camera and object increased the object within the picture became smaller. There a lower number of pixels defined the area of the object. Minor changes of factors influencing the calculations (angle between camera and object, or an error in clicking the contours of the object) would therefore have a higher impact on the area calculations than if more pixels would define the area within the object. For length calculations possible errors while taking the pictures were only linearly integrated. Therefore it was possible, that photogrammetric length calculations were less influenced by higher distances than area calculations are.

From these results I conclude that there is an optimum range of distances for taking the pictures. For photogrammetric analyses of an object of 25 times 140 cm the optimum range is from four to ten meter. This range might be even expanded for photogrammetric length calculations.

During the analysis process the contour of the animal in the picture needed to be marked. This could lead to errors in photogrammetric calculations. In a previous study a noticeable impact of the person marking the edges of the animal in the picture was found (Zein 2010, Müller 2011). In the present study this error was minimized. The contour needed to be marked by an observer only roughly since additionally an edge based segmentation technique (Lankton and Tannenbaum 2008) was used. In the figures (R4, R9) it is seen that there is almost no impact of the marking procedure. This is a great improvement of the photogrammetric technique and results to the fact that the impact of the person marking the contour of the object in the picture can be neglected.

4.3.2 Influence of parameters of pictures, animals and season on accuracy of photogrammetrics

For the application of a photogrammetric method it was important that the animals in the picture are in a comparable position. Especially for sea lions this was difficult. They have various resting positions and very flexible bodies. Therefore different parameters of the animals in the picture were categorized and evaluated for the use of photogrammetrically estimating body parameters. If only the *best pictures* were considered for body length and mass calculations the accuracy (R^2, s.d.) and precision (mean deviation) greatly increased compared to the values of all pictures (table R3, R4; R6, R7; R9, R10). However, if only the *best pictures* were used and the rest of the pictures were excluded, the sample size was drastically lower. Therefore it is discussed in the following which parameters within the picture do not interfere with photogrammetric calculations and can be used additionally to *best pictures*.

<u>Factor picture type</u>

The best accuracy and precision in calculating length and mass of adult and offspring sea lions was derived with pictures taken from ground level (*PG*). Including the picture type *PE* lowered the accuracy drastically even if *PE* pictures were calibrated separately (table R-9). This clearly supports that the worse accuracy values were not due to the *PG* specific calibration. Pictures in the *PE* category were taken while the photographer was staying. Depending on the distance between camera and animal the view on the animal was changed. If the observer took a picture from a higher distance the picture represented an animal from the side view. However, if the picture was taken from a low distance the perspective was changed to a top view. This made photogrammetric calculations difficult since pictures were hardly comparable. Differences between deviation values of *PG* and *PE* calculations were more pronounced in photogrammetric body mass calculations (around 16 %, body length within 5 %) since for body length calculations only the major axis length was considered which should not change a lot with the view.

The best solution for deriving an effective method for calculating animals' body length and mass with the use of pictures is to exclude pictures of the picture type *PE* or to avoid making such pictures. On the other hand, there is also a benefit in taking pictures of the type *PE*: Pictures in the picture type *PE* can be taken slightly faster and easier because the researcher does not need to lie down while taking the pictures. In some studies it might be beneficial to be a little less accurate in length calculation and to gain a larger data set. In this case pictures taken from elevation are a good alternative for length calculations.

In general, I would recommend taking pictures from ground level (*PG*) for photogrammetric calculations. However, using the picture type *PE* might be a good alternative if it is difficult to gain a high number of samples or if a five percent worse accuracy can be accepted. For photogrammetric body mass calculations only the picture type *PG* can be considered to be accurate and precise enough.

<u>Factor body form</u>

Evaluating different body forms was very difficult because the sample size of pictures in only one category was quite low.

For adult photogrammetric body length calculations only pictures with animals in a *good* body form were considered since excluding the other body forms from the *all picture analysis* increased accuracy and precision values and vice versa (table R3). In offspring body length calculations almost the same results were observed, except the results concerning the body form *bent* (figure R5). In the *best picture analysis* the pictures in the body form *bent* were included without drastic changes of the accuracy values. Only the precision (mean deviation) value indicated constant underestimations if pictures in the category bent were included. This could be improved by adding a constant factor to photogrammetric length calculations of offspring. However, this needs to be evaluated further and proved with a higher sample size before used in studies of offspring body length.

For photogrammetric adult body mass calculation there was no picture of the body forms *bent* or *bad* without any other category (problems) interfering. Therefore no conclusion can be drawn. For offspring mass calculations only *bent* pictures could be evaluated additionally. Minimal lower accuracy and precision values were observed while including *bent* pictures. This might be sufficient in studies where the photogrammetric mass determination is used for deriving different mass classes of animals. In this case including pictures of sea lions in the body form *bent* can increase the sample size. For studies concerning the actual body mass of sea lions the accuracy should be as high as possible and pictures in the body form *bent* should be excluded or avoided. This finding is supported by a study of Steller sea lions (Waite et al. 2007). They could show that body posture is a major factor affecting the accuracy of photogrammetric measurements of anesthetized animals. The present study extents this knowledge for wild Galápagos sea lions without the use of anesthetics.

Concluding, I can say that pictures of animals in a straight body form (*good*) derive high accuracy and precision values for photogrammetric calculations in adults and no additional body forms can be included. For offspring additionally the body form *bent* might be considered for calculations if a constant factor is added to the calculated length or a lower accuracy can be accepted.

Factor position

Depending on the side the animals are lying on the area of the animal in the picture can be influenced. This could have affected photogrammetric body parameter calculations. I would have expected that this effect is less pronounced in photogrammetric body length calculations than in body mass calculations because the animals' body length should be independent of the position.

Pictures of animals in the *belly* position derived the most accurate photogrammetric body length and mass calculations (table best R4, R6, R9 and R11). This is supported by findings of the studies of photogrammetrically estimating the body mass of elephant seals (Haley et al. 1991, Bell et al. 1997). There they found that the side area of an animal lying on the belly is the best single variable for photogrammetrically estimating body mass.

Sea lions in the *back* position could be used additionally for photogrammetric calculations. Only slightly worse accuracy and precision values were calculated while including pictures of the position *back* (table best R4, R6 and R9). This is contrarily to the findings of a study of photogrammetrics on Hawaiian monk seals (McFadden et al. 2006). There they found that pictures of animals lying entirely on the back lead to an extreme underestimation of calculated surface area and body length. This difference in the findings of the use of the position *back* for photogrammetrics can be due to species specific body shapes. Hawaiian monk seals belong to the family of the earless seals (*Phocidae*) whereas Galápagos sea lions are eared seals (*Otariidae*). Major differences in body characteristics are due to the fact that sea lions are more adapted to a faster movement on land than Phocids are. This can be seen in the flexibleness of their bodies and a less fat and round body. For Galápagos sea lions the *back* position seems to be similar in shape to the position *belly* and can therefore be used for photogrammetric body length and mass calculations of adults.

Using pictures of the category *side* position derived slightly worse accuracy values than including *back* position pictures for adult body length calculations (table R4). Changes in body form could occur more pronounced if the animal was lying on the side than on the belly or back. If a dorsal-/ventral section of the animal was considered, no true circularity of cross section could be found but a more elliptical shape. This could lead to slight changes in body form if the animal was lying on the side and could therefore have a negative impact on the accuracy of photogrammetric body length calculations. If too many pictures of categories with slightly worse accuracy values were included the overall representation of the photogrammetric calculated body length became imprecise. For highly accurate representations of the actual animals' body length researchers should exclude pictures of animals lying on the side. However, as mentioned above in other categories, it might be beneficial including pictures in categories which derive slightly less accuracy values but increase the sample size.

Pictures of the position category *side* had a negative impact on adult body mass calculation (table R9). The asymmetric section of the animal led to a problem in comparison of the side areas if the animal was lying in different positions. Therefore a combined analysis of pictures of the positions *side* and *belly* derived worse accuracy values. The accuracy of the photogrammetric mass determination of *side* position pictures did not increase if a separate calibration for the pictures in the category *side* was made and analyses are repeated for *side* position pictures only. This indicates that the *side* position of the animals seems to be very variable and therefore not useful for photogrammetric body mass calculations of Galápagos sea lions.

For offspring length calculations the same findings as for adults existed. *Belly* and *back* position pictures were included in photogrammetric calculations. *Side* position pictures could be included depending on sample size and on the degree of accuracy which should be achieved.
For photogrammetric body mass calculations of offspring only *belly* position pictures could be used. This is different to findings in adults, where also *back* position pictures were included. However, the same results as for photogrammetric offspring body mass calculations in the present study are found in the study of Hawaiian monk seals (McFadden et al. 2006). It can be that the blubber of Galápagos sea lion offspring is thicker than for adults. This could make them look more round and therefore more similar to monk seals. On the other hand thicker blubber could be a general characteristic of offspring pinnipeds and lead to different findings in offspring than in adults. However, the sample size of pictures of offspring in the *back* position was only two. It could be that the sample size was too low to draw a final conclusion. This should be further tested.

Factor problem

The evaluation of the category problem was limited to adults since no problem pictures of offspring were made.

In a previous study of Bell et al. (1997) it was assumed that the animals have to lie on firm and packed surface like sand rather than in grass. This could be proved with the current study. If a part of the animals' body in the picture is covered, the tracing procedure of the animals' contours becomes very difficult. This is the fact if an animal is lying in the grass. Additionally in grass it cannot be spotted by the researcher if the underground is even.

Lying in a hole can highly influence body posture and therefore body length and mass calculations. In the present study a negative influence of pictures of adult animals lying in grass was found on photogrammetric body length and mass calculations, in spite of a low sample size.
Additionally it was impossible to analyze pictures of sea lions lying on lava stones. The color is very similar to animals' body color. That makes the tracing impossible since little cracks or irregularities around the animal were misinterpreted by the program as a part of the animals' body during the tracing process of the contours.
Overall, I conclude that for accurate photogrammetric determination of body length and mass the contours of the animal in the picture have to be visible and the color of the animal and the background should be effectual different.

Sea lions have very flexible resting positions which make an individual photogrammetric comparison very difficult. Even if the body appears mostly straight the head can be turned into various positions. This influences the pictured body length and area and should have had an impact on photogrammetric calculations. The results of the present study proved this expectation. Using a picture of the problem category *head* for photogrammetric body length and mass calculations derived high deviations between measured and calculated values. Further studies of photogrammetric determination of body morphometrics of sea lions should pay attention to a deviation of animals *head* position while taking or sorting the pictures.

The more categories are defined the less is the sample size of pictures within a single category. Therefore the number of categories should be limited. A category summarizing all little problems within a picture was named problem *another*. Those were pictures of animals which were lying in a small hollow, have only a little part of the contour covered or pictures of animals with unusual little deviation of body form (figure M5, right). These factors had no impact on photogrammetric calculations and can be further disregarded.

Factor season

The results of the present study indicated that the impact of a greater time span between manually measured and photogrammetrically calculated data acquisition can be neglected for photogrammetric body length determination (table R4) but not for body mass (table R9) calculations. These differences in body length and body mass changes were due to the biology of the animal. Galápagos sea lions grow throughout their life time. Short time changes in food supply do not greatly affect growth. Therefore it was possible to use manually measured data of animal's body length from a previous season for comparison with photogrammetrically calculated body length. The body mass of Galápagos sea lions can change during a short time. Especially on the Galápagos Islands the food abundance can greatly vary due to El Niño. Then animals depend on their energy reserves in terms of fat. This can lead to changes in the body mass of the animals. Also if a sea lion female gives birth to an offspring the body mass changes within a short time span. For comparison of manual and photogrammetric body mass calculations the time span should be smaller than 2-3 months and care should be taken with the photogrammetric analysis of adult females in the season when they give birth to offspring.

That the different changes of body length and mass over time could be detected with this photogrammetric method supports the use of this method. Only highly accurate and precise estimated body parameters could have been used to detect these changes.

4.4 Application to body condition

The physiological state of an animal can be an indicator for the ability of an individual to cope with intrinsic and extrinsic factors. Therefore it can be used for studying various topics ranging from comparisons of individual differences to the impact of environmental changes on animals and life history strategies. A common way of evaluating the physiological state of an animal is by calculating the body condition. The comparison of the manually measured and photogrammetrically calculated body parameter of animals derived similar results. The equations and correlation coefficients of the plotted lines were closely related. And there were no significant differences for the condition values. This indicates small differences between the results of the two measurement procedures and shows that the photogrammetric measurements are precise enough to calculate body conditions. This is a great support for the use of photogrammetrics for body parameter calculations in sea lions and could be more considered in further studies of various species.

5. Summary

For Galápagos sea lions a photogrammetric body mass determination technique was developed and a photogrammetric body length determination technique was improved. For researchers the method of photogrammetrically estimating animals' body parameters is easy to accomplish in the field and the analyses of the pictures are fast. For the animals this method minimizes the disturbances while collecting morphometric data. Only a few animals need to be captured for weighing and measuring the size for calibration. As a result of the present study I could show that this method derives highly accurate and precise results for estimations of animals' body length and mass. Comparison with the accuracy of other photogrammetric studies of body length and mass on wild not narcotized pinnipeds shows that the photogrammetric method used in the present study derives the best values for accuracy and precision. Also if animals' parameters are measured manually the error is only slightly smaller compared to the photogrammetric method. Further the application of photogrammetric estimated body parameters on calculations of body condition was tested. The differences of manually and photogrammetric residual body condition values was not significant. That indicates that this method can be established in a lot of different fields of study. Overall these results make the method of photogrammetrically estimating body morphometrics a perfect alternative to manual measurements.

However, there are several factors influencing the accuracy of photogrammetric measurements. Some of them should be avoided because of a high impact on the accuracy. Pictures should not be taken of animals which are bended more than 15 degrees with the head or tail end. Furthermore it could be shown that pictures of animals lying in the grass or with a bended head could not be used for accurate calculations. For mass calculations additional pictures of animals lying on the side and pictures taken from elevation cannot be considered for photogrammetric calculations. For body length calculations only slight deviations of accuracy values are found if the picture was taken from elevation or if pictures of animals lying on the side were taken. In this case it can be considered to include these factors to increase the sample size if the accuracy does not need to be very high. While

taking the picture the researcher needs to be aware of the distance and angle between camera and object. There is an optimum distance for taking the picture of four to ten meter for an object of 140 cm of length. Also it should be avoided to deviate from a 90 degree angle between the camera and the longitudinal axis of the animal's body. For this it is sufficient to use the human sense of vision. However, there are factors which can be neglected while using the photogrammetric method for estimation of body morphometrics. In the present study I could show that pictures of animals lying on the back, with only a little part of the body covered or lying in a little hollow can be used for photogrammetric calculations in most of the cases. This is a great advantage which can increase the sample size of pictures. Also no impact of a change in object angle (animals lying on slope beaches) or the marking procedure of the contours of the animals in the picture could be found.

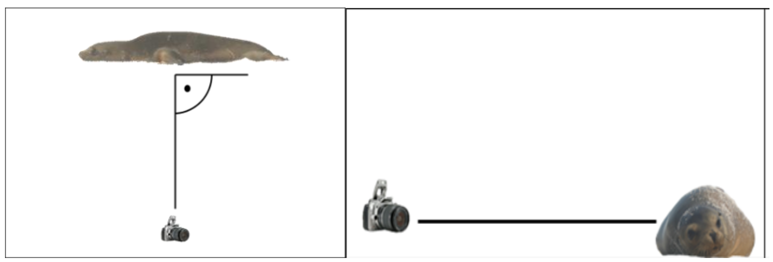
Some questions remain unsolved and should be tested in further studies. First a higher sample size of pictures of both sexes could help clarifying the differences of sexes on photogrammetric calculations. In addition it could derive more accurate calibrations if animals of the whole range of sizes could be captured. Furthermore a higher sample size of offspring pictures could help improving the photogrammetric calculations and support the finding of the present study.

In the future it could be possible that developments in camera techniques further increase the application possibilities of the photogrammetric method. Nowadays the use of high definition cameras could already improve the photogrammetric method used in the present study. This can increase the accuracy and the range of optimum distance between camera and animal. However, even with the material used in the present study the photogrammetric determination for body length and mass is a great method for Galápagos sea lions. This method can be applied for various species and can therefore increase the knowledge in various fields of studies.

GUIDELINE
Photogrammetric determinations of body length and mass of sea lions

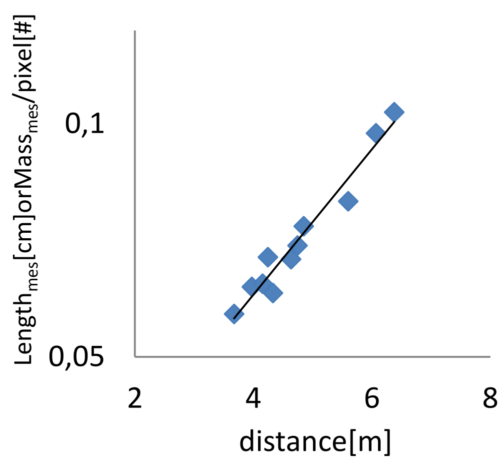
PROCEDURE

1. Taking pictures of animals and measuring the distance between camera and object. While taking the pictures the researcher has to be ideally in a 90 ° angle to the longitudinal axis of the animal's body and pictures of the animals should be made in same height as the animal itself.



Additionally body length and mass of the photographed animals have to be manually measured.

2. Using these values for calibration:



Converting the equations derived from calibration for further calculations of body length (1) and mass

(1) Body length = (a*distance-b)*pixel$_{length}$

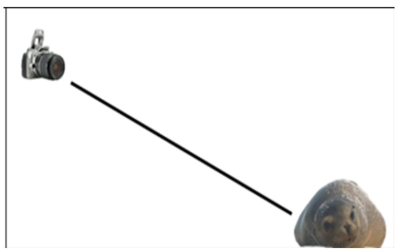
(2) Body mass = (a*distance^b)*pixel$_{area}$

DO´S

Animals should lie straight, on the belly or back, on a flat underground. Contours can be partly covered and animals can lie a little hollows.



MAYBE`S



For length calculations only

Side position and pictures taken from a different height can be included but lower the accuracy a little

For Offspring only

Including bent body forms for length (+adding a constant value) mass (less accurate) calculations

DONT'S

- Head or back end should not be bent with the more than 15 degrees
- No deviation in head position

- Body contours should be visible


- Side position cannot be used for mass calculations

Appendix

<u>Calibration – pole</u>

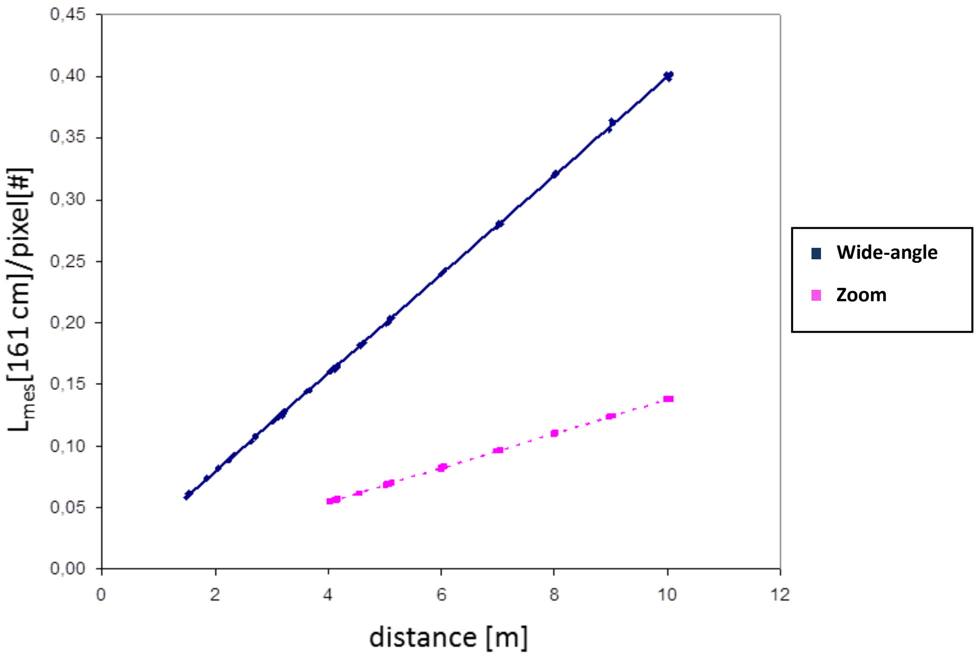


Figure A1 Calibration for the pole (for straight line equation and R^2 values see table R1). This figure was made by Dr. Birte Müller.

<u>Calibration – cardboard</u>

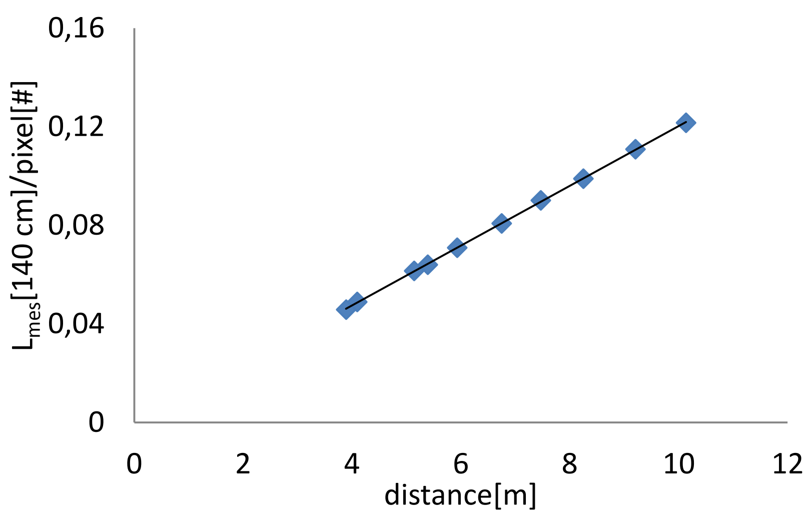


Figure A2 Calibration for the cardboard length (for straight line equation and R^2 values see table R1).

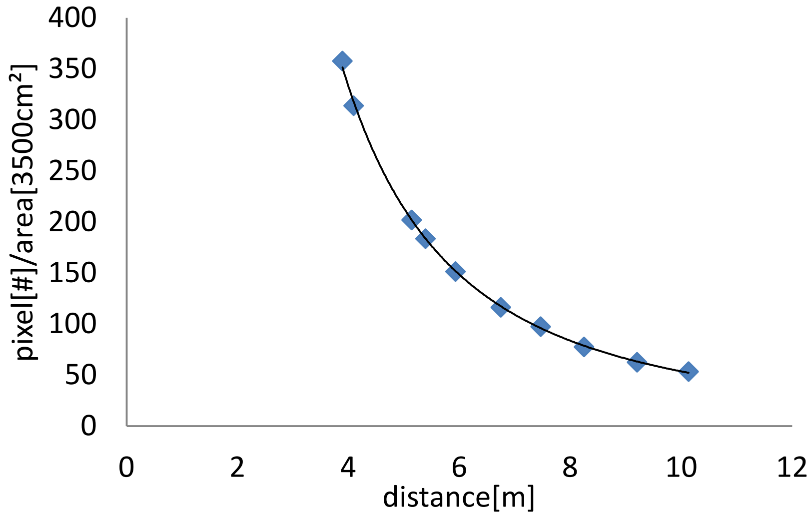


Figure A3 Calibration for cardboard area (for exponential equation and R^2 values see table R1).

<u>Calibration – *animals*</u>

<u>Length - adults</u>

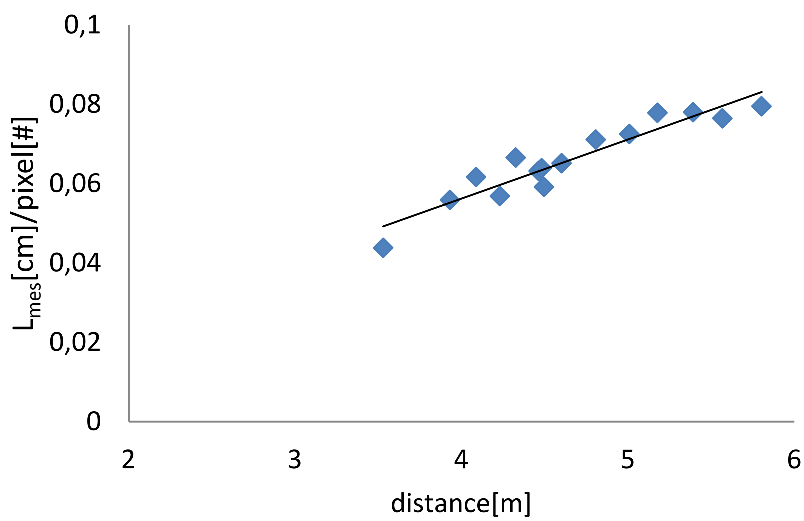


Figure A4 Calibration for the method *animals* for adult body length and pictures in picture type *PE* (for straight line equation and R^2 values see table R1).

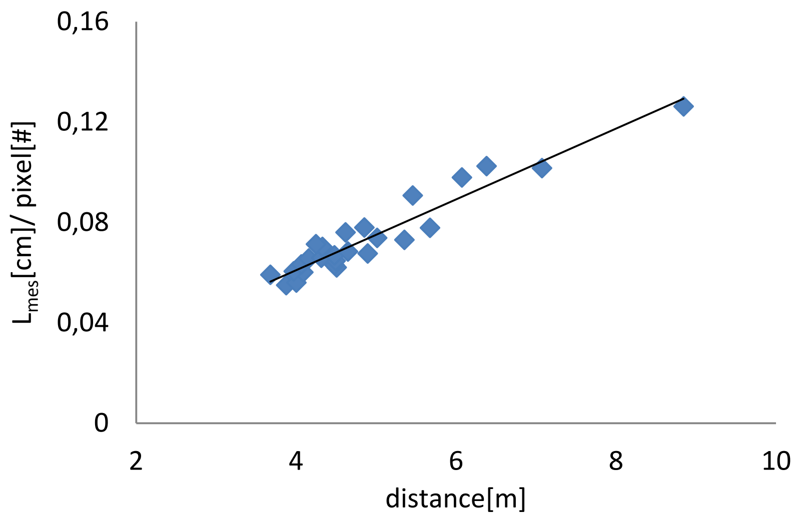


Figure A5 Calibration for adult body length calculations for the method *animals* for picture types *PG* and *PE* (for straight line equation and R^2 values see table R1).

Length – offspring

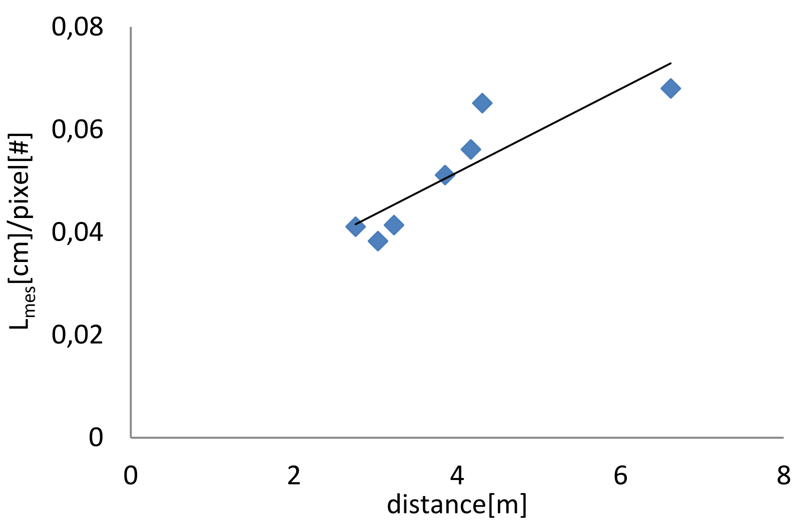


Figure A6 Calibration for offspring body length calculations for the method *animals* for picture type *PE* (for straight line equation and R^2 values see table R1).

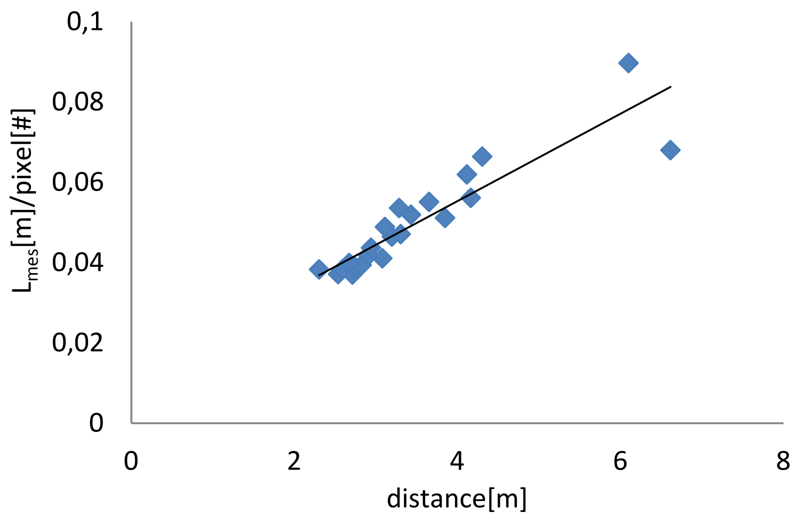


Figure A7 Calibration for offspring body length calculations for the method *animals* for picture types *PG* and *PE* (for straight line equation and R^2 values see table R1).

Mass – adults

Correlation *pole*

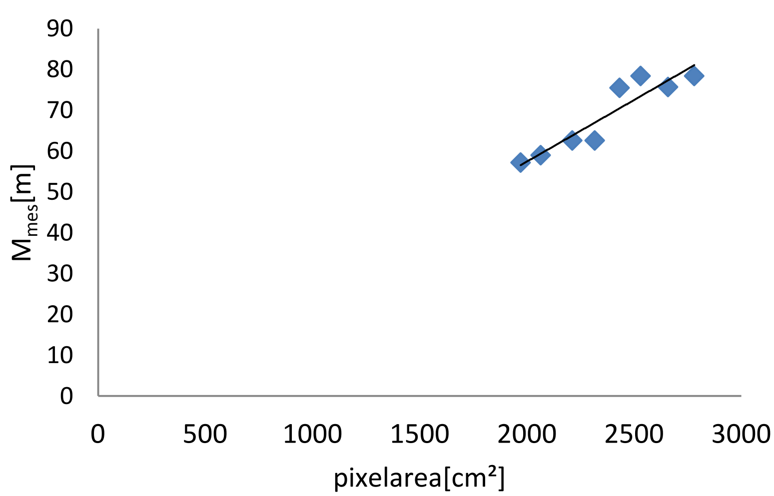


Figure A8 Correlation between measured body mass of the adults and calculated pixelarea of the method *pole* (for straight line equation and R^2 values see table R7).

Correlation *cardboard*

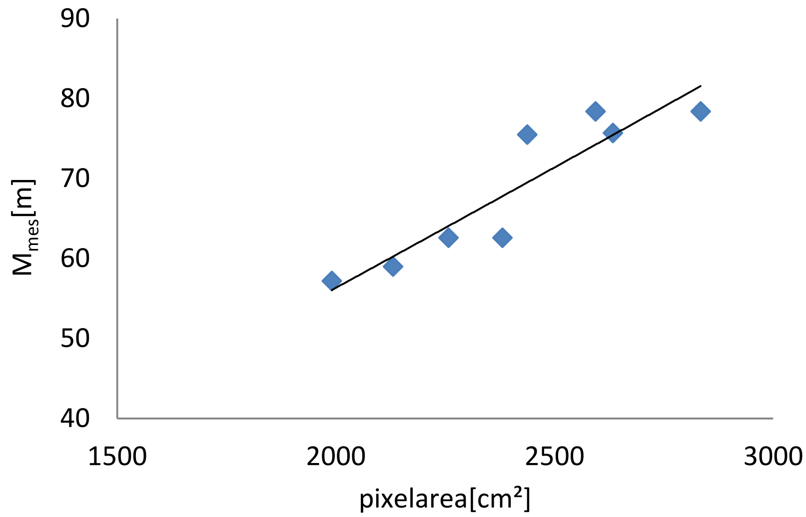


Figure A9 Correlation between measured body mass of the adults and calculated pixelarea of the method *cardboard* (for straight line equation and R^2 values see table R7).

Calibration *animals*

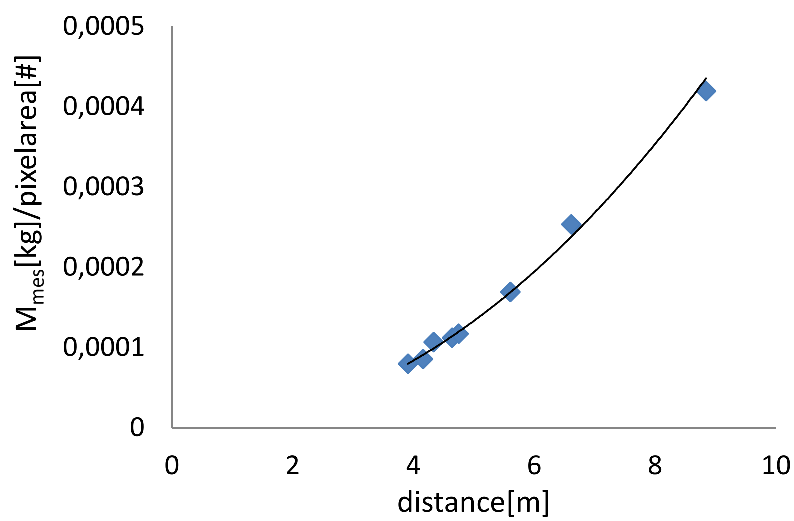


Figure A2 Calibration for adult body mass calculations for the method *animals* for picture type *PG* (for exponential equation and R^2 values see table R7).

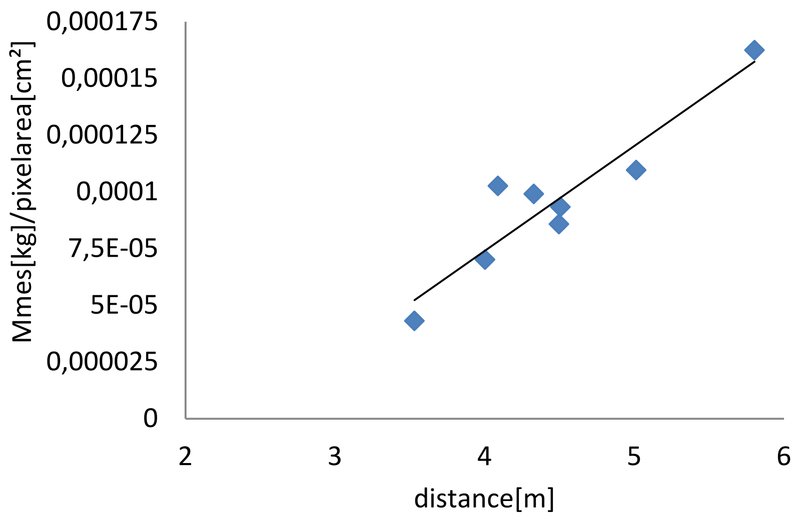


Figure A3 Calibration for adult body mass calculations for the method *animals* for picture type *PE* in the positions belly and back (for straight line equation and R^2 values see table R7).

Mass – offspring

Correlation *pole*

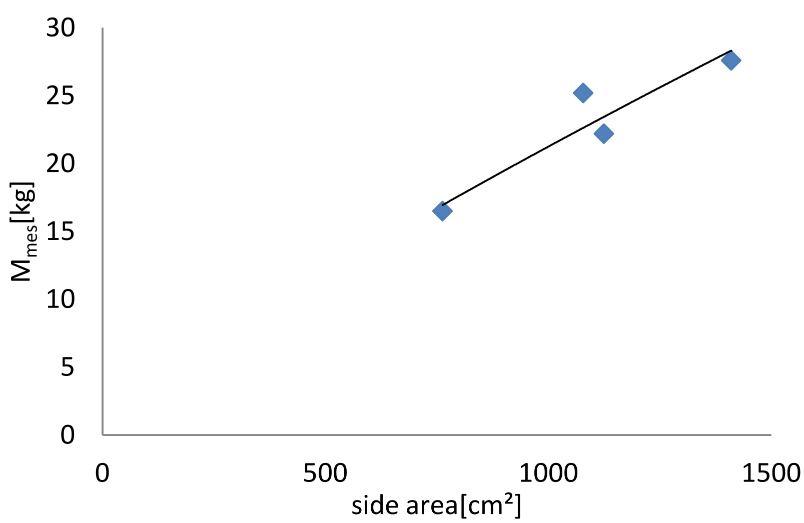


Figure A4 Correlation between offspring body mass and calculated side area for the method *pole* (for straight line equation and R^2 values see table R7).

Correlation *cardboard*

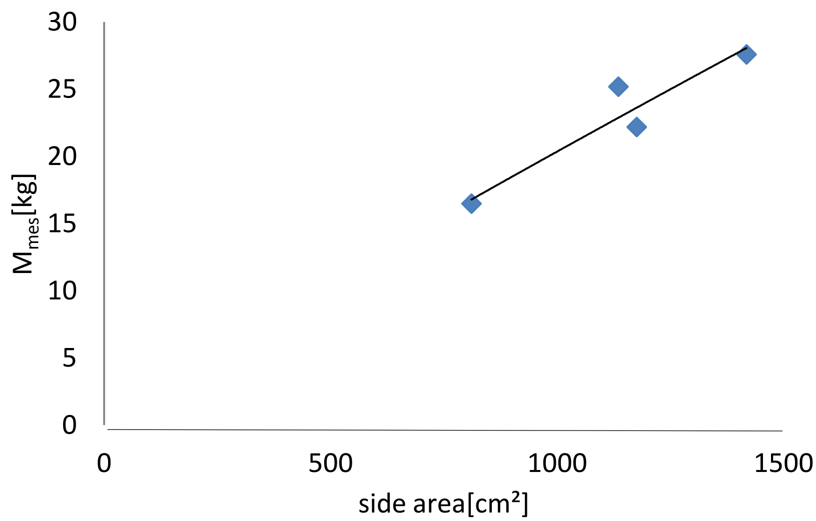


Figure A5 Correlation between offspring body mass and calculated side area for the method *cardboard* (for straight line equation and R^2 values see table R7).

Calibration *animals*

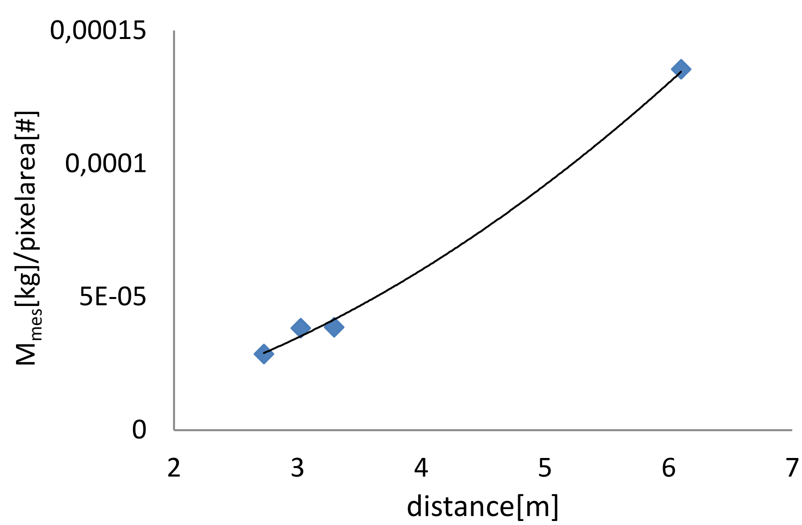


Figure A6 Calibration for adult body mass calculations for the method *animals* for picture type *PG* (for exponential equation and R^2 values see table R7).

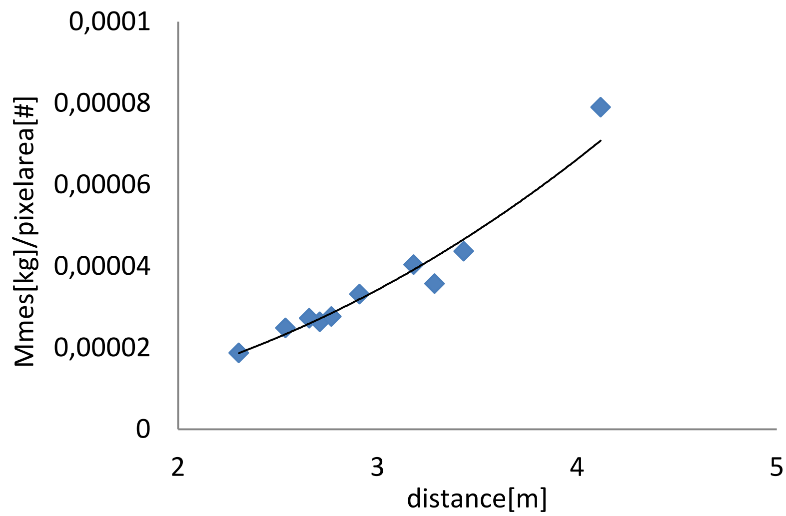


Figure A7 Calibration for offspring body mass calculations for the method *animals* for picture type *PG* and only position side (for exponential equation and R^2 values see table R7).

Testing for errors in data acquisition

Length

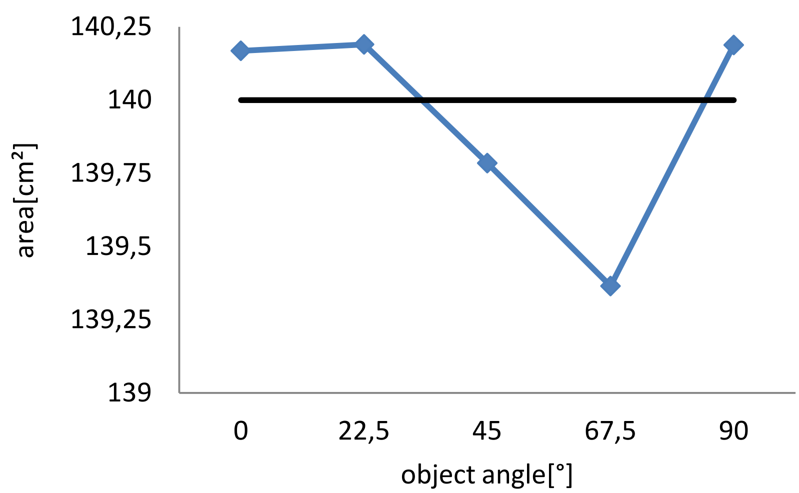


Figure A8 Impact of a change in object angle (object rotation through the object center vertical to the image plane) on calculated length.

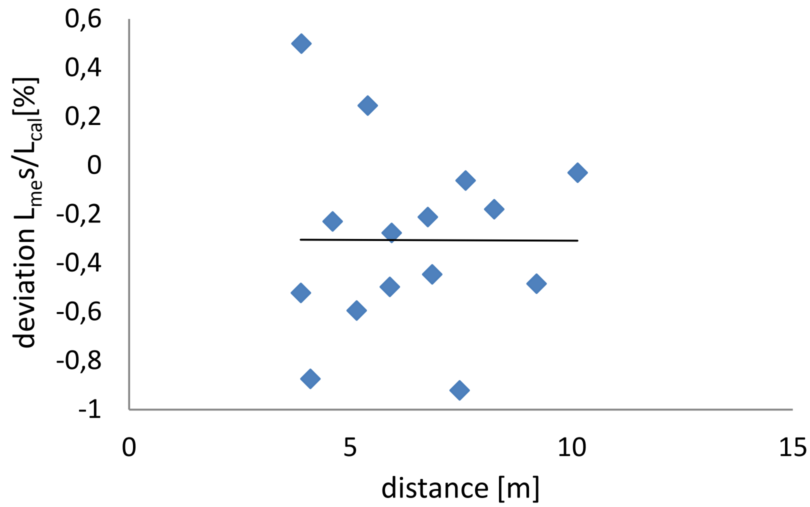


Figure A9 Impact of a change of distance between camera and object on calculated length.

<u>Area</u>

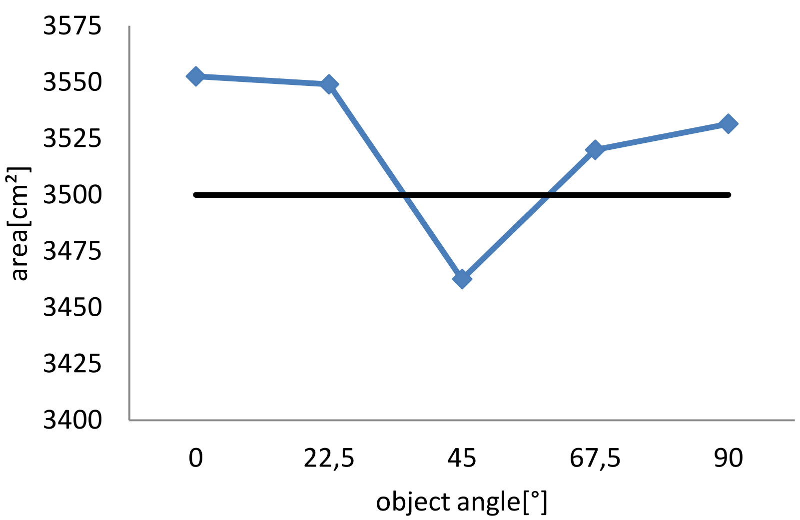


Figure A10 Impact of a change in object angle (object rotation through the object center vertical to the image plane) on calculated area.

Figures sex differences

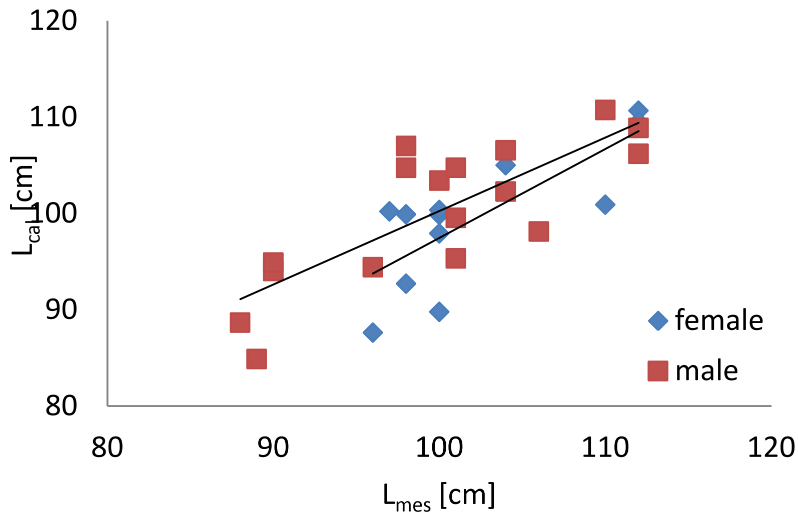


Figure A19 Sex differences of the calculated and measured length of offspring (female y=0.9232x+5.1349, R^2=0.591; male y=0.7637x+23.891, R^2=0.642).

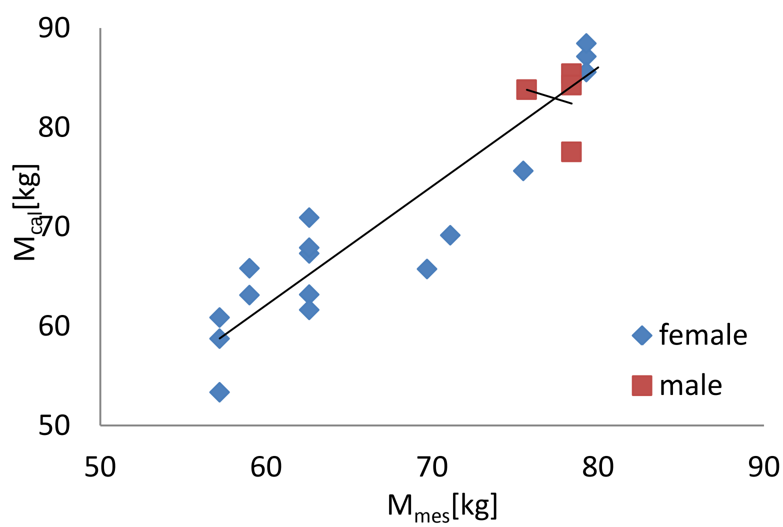


Figure A11 Sex differences for the calculated and measured body mass of adults (males y= -0.5183x + 123.05, R^2=0.039; females y= 1.1971x - 9.7017, R^2=0.857).

Table all picture analysis for adult body mass calculations

Table A1 Evaluation of the accuracy and precision of calculated adult body mass compared to measured body mass and the impact of animals' positions and body form parameters in the picture, picture parameters and *season*. All pictures were used and evaluation of the impact of parameters on calculations was done by excluding parameters separately.

	factors excluded	n individuals	n pictures	R^2	$\bar{x}$ deviation M_{mes}&M_{cal} [%]	s.d. [%]
all		42	161	0.324	5.49	18.59
picture type	PG	25	48	0.494	19.76	18.34
	PE	30	113	0.399	-0.57	15.10
body form	bended	41	133	0.423	7.72	18.08
	bad	42	139	0.323	6.45	18.10
	bended, bad	39	111	0.448	9.37	17.10
	good, bad	12	28	0.135	-5.10	17.56
position	belly	30	91	0.461	6.00	19.14
	back	40	147	0.325	3.59	17.75
	side	31	84	0.254	8.26	19.14
	belly, back	27	77	0.484	2.47	17.59
	belly, side	7	14	0.796	25.43	15.67
	back, side	26	70	0.213	4.83	17.96
span picture-weighing	season	33	115	0.420	7.59	17.98
problem	grass	41	152	0.358	5.00	18.31
	head	40	126	0.304	7.05	17.73
	another	35	119	0.317	6.70	19.16
	all	30	86	0.355	7.57	17.52

Appendix

Written Matlab programs

PROGRAM MAIN MENU

```
close all
clear all

%get directory
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\analyse';
%current directory
cd(dir_main);
%list of all the folders in m
dir_list = dir(dir_main);
%first two have to be deleted because they remain . and ..
dir_list(1:2) = [];

% extracting the files which is needed (but not loading)
pic_list = [];
for i = 1 : length(dir_list)
    if strfind(char(dir_list(i).name),'IMG')
        pic_list = [pic_list ; dir_list(i)];
    end
end

%create a menu for a choice of three different program parts
decide=menu('What do you want to do?', 'get directory and mask', 'run stats', 'end');

switch decide
case 1

%search for first picture in file and save this in now
for j = 1 : length(pic_list)

    %save current filename
    now = pic_list(j).name;
    %save current Photonumber
    nophoto=pic_list(j).name(5:8)

bild1=now;
I=imread(bild1);
%create a copy of picture 5 times smaller and in gray
I1=imresize(I,.2);
I1 = rgb2gray(I1);
%show picture
imshow(I1)
%choose relevant part of the picture with a rectangular mask
%press return afterwards
I2=imcrop(I1);
%function manual select
%locate the body of the animal by clicking along the contours of the animal
```

```
%parts of an animal’s contour were the contrast between animal and background is low have to have lower
distances between clicks
%mask contains the body of the current pictures animal
mask = manualSelect(I2);

%save picture, mask and I2
save([bild1(1:end-4),'_maskI2'], 'mask', 'I2');
%delete not further used values and close everything
clear I
clear bild1
clear I1
clear I2
clear mask
clear now
close all;
end

% second program part 'run stats'
case 2
clear all

%get directory
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\analyse';
%current directory
cd(dir_main);
%list of all the folders
dir_list = dir(dir_main);
%first two have to be deleted because they remain . and ..
dir_list(1:2) = [];

% extracting the files which is needed (but not loading)
pic_list = [];
for i = 1 : length(dir_list)
    if strfind(char(dir_list(i).name),'maskI2')
        pic_list = [pic_list ; dir_list(i)];
    end
end

%load the files out of pic_list
%for every mask do the following
for j = 1 : length(pic_list)
    close all
    mat_var = load(pic_list(j).name);
clear I2 I3 mask;
I2= mat_var.I2;
mask= mat_var.mask;

% the part of I2 which is outside of the animal’s body (mask) gets brighter
% higher contrast reduces errors in tracing
```

```
for i=1:size(I2,1)
   for a=1:size(I2,2)
       if mask(i,a)==1
           I3(i,a)=I2(i,a)*1.5;
       elseif mask(i,a)==0
           I3(i,a)=I2(i,a);
        end
    end
end

%create figure
figure
title('compare shadow cleaning/before')
subplot(2,1,1)
imshow(I2)
subplot(2,1,2)
imshow(I3)

%start tracing of animals contour
%this function implements the paper: "Localizing Region Based Active Contours" By Lankton and
Tannenbaum.
% Here region-based active contour energies are localized in order to handle images with non-homogeneous
foregrounds and backgrounds.
seg = localized_seg(I3,mask,20,20);
animal=pic_list(j).name
%output sidearea, perimeter, major axis und minor axis
stats = regionprops(~seg, 'Area','Perimeter','MajorAxisLength', 'MinorAxisLength')
save([pic_list(j).name(1:end-10),'stats'], 'seg', 'stats','I2','mask');
%mat_var empty again
mat_var = [];
    pause
end

%third part of program 'end'
    case 3
end
```

PROGRAM AREA-LENGTH CALCULATIONS

```
%import Excel sheet
[zahl,text,alles] = xlsread('pic_data_sp12_newpluscatpicOHNE.xlsx','Tabelle1');

%get directory
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\analyse';
%current directory
cd(dir_main);
%list of all the folders
dir_list = dir(dir_main);

%create folder with all Image_stats folder names
```

```
statsfolder_list = [];
for i = 1 : length(dir_list)
    if strfind(char(dir_list(i).name),'stats')
        statsfolder_list = [statsfolder_list ; dir_list(i)];
    end
end

%data of labels of copied Excel sheet ‘alles’ in a new variable
PhID=[];
for i=2:length(alles)
PhID=vertcat(PhID, alles{i,2});
end

%%%get area and length%%%
%for loop go to statsfolder_list take first and do following
%do this for every file
%create file resultsfilesp12
resultsfilesp12=[];

for i = 1 : length(statsfolder_list)
    %A=... only take parts of foldernames statsfolder_list which can be found in copied Excel sheet
    A = statsfolder_list(i).name(5:8);
    %string to number conferts text in number 0`s get droped
    B=str2num(A);
    A=B;
    %index contains row+1 from sheet ‘alles’ for current value
    index=find(PhID==(A));

if index > 0;
    zoomfaktor=0.0139;

        %get the first name
        folder=open(statsfolder_list(i).name);
        %get the stats data of i animal
        animaldata=folder.stats;
        %save current
        name=statsfolder_list(i).name
        %calculate
        pixellength=animaldata.MajorAxisLength*5;
        pixellengthminor=animaldata.MinorAxisLength*5;
        pixelarea=animaldata.Area*25;
        reallength=(zoomfaktor*alles{index(1,1)+1,12}-0.0016)*(pixellength);
        realarea=(((zoomfaktor*alles{index(1,1)+1,12}-0.0016))^2)*(pixelarea);

        resultsfilesp12(index(1,1)+1,:)=horzcat(alles{(index(1,1))+1,2},realarea,reallength);

        %add current information of current file to a file
        save([statsfolder_list(i).name(1:8),'area'], 'realarea','reallength');
```

```
elseif index == 0
end
end

%save file
save('resultsfilesp12', 'resultsfilesp12');
%save as MS Excel file
xlswrite('resultsfilesp12.xls',resultsfilesp12);
```

PROGRAM COMBINE

```
close all
clear all

%%get directory
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\combine\';
%%current directory
cd(dir_main);

%import two Excel sheets
[zahl,text,alles]=xlsread('new_data.xlsx','tabelle1');
[zahlAN,textAN,allesAN]=xlsread('image_info.xlsx','tabelle1');

%for loop> do the following for all columns
%two sheets ‘alles’ and ‘allesAN’
%go to one column in one sheet and compare it to the first row in the other sheet (i-loop)
for s = 2 : length(allesAN)

    for i = 2 : length(alles)
        if alles{i,2}==allesAN{s,2}
            %if you find a match write the ID of the animal in the main sheet 'alles'
            %add additional factors of one sheet
            alles{i,18}=allesAN{s,3};
            alles{i,19}=allesAN{s,4};
            alles{i,20}=allesAN{s,5};
            alles{i,21}=allesAN{s,6};
        end
    end
end

%save file
save('alles','alles');
%save file as MS Exel file
xlswrite('trial02.xlsx',alles);
```

PROGRAM CLASSIFICATION 1

```
close all
clear all

%get directory
```

```
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\catpics';
%current directory
cd(dir_main);
%list of all the folders
dir_list = dir(dir_main);
%first two have to be deleted because they remain . and ..
dir_list(1:2) = [];

% extracting the file which is needed (but not loading)
pic_list = [];
for i = 1 : length(dir_list)
   if strfind(char(dir_list(i).name),'IMG')
      pic_list = [pic_list ; dir_list(i)];
   end
end

%create the new file with new info’s
image_info = {'filename','no photo','pic type(1-side,0-back,3-garbage)','pic flipper bended(0. no,1yes good,2yes
medium,3yes bad)','pic category','angle problem(1 Yes,0 No)'};

% load the files out of pic_list; run for loop for every file
for j = 1 : length(pic_list)
   close all
   %save current filename
   now = pic_list(j).name;
   %save current photo number
   nophoto=pic_list(j).name(5:8)
   imshow (now)

   %get the three classifications 'pic type','pic category','pic flipperbended'and another problem over a new
window
   %form a menü window and ask for the first new input.
   %menu picture type
   decide=menu('What is the picture type?', 'side', 'back', 'garbage');
   % Picture type -- 1. Side -- 0. Back -- 3.Garbage
   switch decide
      case 1
         ptype=1;
      case 2
         ptype=0;
      case 3
         ptype=3;
   end

   %menu bended flipper
decide=menu('Is the flipper bended under body?', '0 no','1 yes -good head/body position 0°','2 yes –medium
head/body position<15°','3 yes -bad head/body position>15°');
   % flipper bended  -- 0. no-- 1. yes good -- 2.yes medium -- 3.yes bad
   switch decide
```

```
        case 1
            pflip=0;
        case 2
            pflip=1;
        case 3
            pflip=2;
        case 4
            pflip=3;
    end

    if pflip==0

%menu body form
if ptype==1
decide=menu('What is the body form?', '1  head:0°,tail:<0°', '2  head:<16°,tail:<16°','3   opposite-head:<40°,tail:<40°','4  same side-head:<40°,tail:<40°');
        switch decide
            case 1
                pcatg=1;
            case 2
                pcatg=2;
            case 3
                pcatg=3;
            case 4
                pcatg=4;
        end

%menu body category only if picture is taken from the back/front
    elseif ptype==0
decide=menu('(back pictures)What is the picture category?', '1  good°', '2  bad animal position','3 different problem');
        switch decide
            case 1
                pcatg=1;
            case 2
                pcatg=2;
            case 3
                pcatg=3;
        end
    end

    elseif pflip>0
        pcatg=0;
    end

    %menu angle problem
    decide=menu('is there a visual noticeable angle-camera problem?', '0 No','1 Yes');
    switch decide
        case 1
```

```
        angprob=0;
      case 2
        angprob=1;
    end

    %write the picture file and the picture number and 4 new infos of the
    %current pic in a file, use for every info the next row
    image_info = [image_info;{now,nophoto,ptype,pflip,pcatg,angprob}];
    save('image_info','image_info');
    close all;
end

%save file as MS Exel file
xlswrite('image_info.xlsx',image_info);
```

PROGRAM CLASSIFICATION 2

```
close all
clear all

%get directory
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\graskopfprobaussort';
%current directory
cd(dir_main);
%list of all the folders
dir_list = dir(dir_main);
%first two have to be deleted because they remain . and ..
dir_list(1:2) = [];

% extracting the file which is needed (but not loading)
pic_list = [];
for i = 1 : length(dir_list)
    if strfind(char(dir_list(i).name),'IMG')
        pic_list = [pic_list ; dir_list(i)];
    end
end

%create the new file with new info's about position
image_info = {'filename','no photo','belly1 back2 side3 nothing0'};

% load the files out of pic_list; run for loop for every file
for j = 1 : length(pic_list)
    close all
    %save current filename
    now = pic_list(j).name;
    %save current photo number
    nophoto=pic_list(j).name(5:8)
    imshow (now)

    %form a menu window and ask for new input. click button for
```

```
    %case 1 to 4
    decide=menu('what is the body position?','belly 1' , 'back 2', 'side 3','nothing 0');

    switch decide
        case 1
            BR_Lage=1;
        case 2
            BR_Lage=2;
        case 3
            BR_Lage=3;
        case 4
            BR_Lage=0;
    end

    %write the picture file, picture number and body position of
    %current pic in the file, use for every info the next row
    image_info = [image_info;{now,nophoto,BR_Lage}];
    save('image_info','image_info');
    close all;
end

%save file as MS Excel file
xlswrite('neualle3lagen.xlsx',image_info);
```

PROGRAM CLASSIFICATION 3

```
close all
clear all

%get directory
dir_main = 'C:\Dokumente und Einstellungen\localadmin\Desktop\springdata\graskopfprobaussort';
%current directory
cd(dir_main);
%list of all the folders
dir_list = dir(dir_main);
%first two have to be deleted because they remain . and ..
dir_list(1:2) = [];

% extracting the files which is needed (but not loading)
pic_list = [];
for i = 1 : length(dir_list)
    if strfind(char(dir_list(i).name),'IMG')
        pic_list = [pic_list ; dir_list(i)];
    end
end

%create the new file with new info's
image_info = {'filename','no photo','gras problem(0 no, 1yes)','head problem(0 no, 1yes)','another problem(0
No, 1 Yes)'};
```

```
% load the files out of pic_list; run for loop for every file
for j = 1 : length(pic_list)
    close all
    %save current filename
    now = pic_list(j).name;
    %save current photo number
    nophoto=pic_list(j).name(5:8)
    imshow (now)

    %form a menu window and ask for the first new input.
    %click button for yes nor for now
    decide=menu('Is there a grass problem?','no 0' , 'yes 1');
    % gras problem -- 1. yes -- 0. no
    switch decide
        case 1
            gprob=0;
        case 2
            gprob=1;
    end

    %menu head problem
    decide=menu('Is there a head problem?', '0 no','1 yes ');
    % head problem  -- 0. no-- 1. yes
    switch decide
        case 1
            hprob=0;
        case 2
            hprob=1;
    end

    %menu another problem
    decide=menu('Is there another problem?', ' 0 no', '1 yes');
    switch decide
        case 1
                anprob=0;
        case 2
                anprob=1;
     end

    %write the picture file, picture number and 3 new info’s of the
    %current pic in a file, use for every info the next row

    image_info = [image_info;{now,nophoto,gprob,hprob,anprob}];
    save('image_info','image_info');
    close all;
end

%save file as MS Excel file
xlswrite('grasprobsorting.xlsx',image_info);
```

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Declaration of independent work

I declare that I wrote this master thesis on my own. I did not use any other resources than the denoted ones. All contained figures, tables and program codes are written by me if not stated otherwise.

Bielefeld, May 15, 2013

Beate Zein